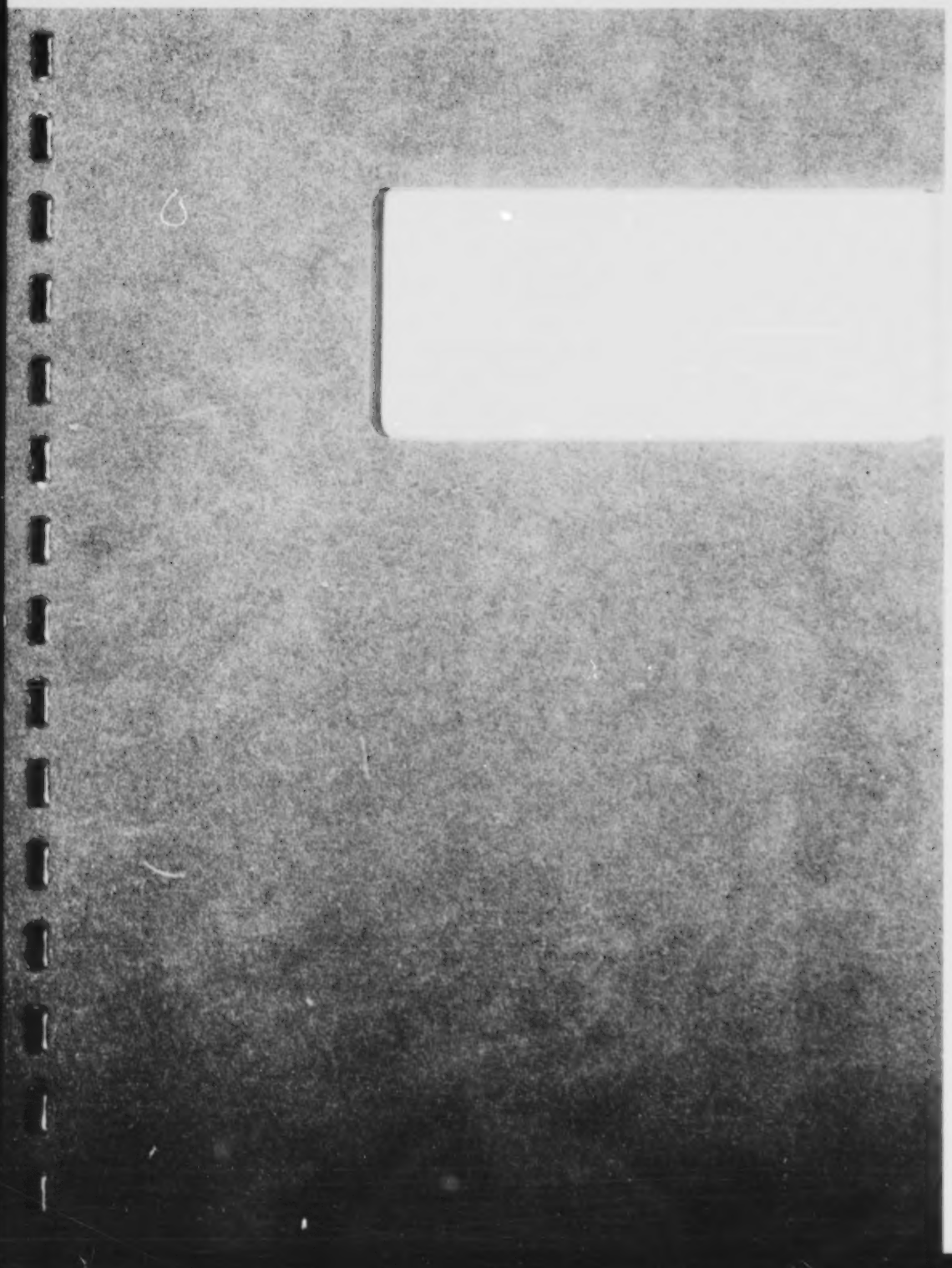
Final report

OWMC
Ontario
Waste Management
Corporation

A provincial crown corporation



Gartner
Lee
Limited

SITE ASSESSMENT - PHASE 4B:

GEOLOGY, HYDROGEOLOGY, AND GEOTECHNICS, GROUND WATER MANAGEMENT STRATEGIES; IMPACT MANAGEMENT, MONITORING, CONTINGENCIES AND FACILITY DECOMMISSIONING

Prepared for

The Ontario Waste Management Corporation

Submitted By

Gartner Lee Limited

December, 1987

Gartner Lee Limited

140 Renfrew Drive,
Markham, Ontario
L3R 6B3
Telex 06-986278
Fax (416) 477-1456

(416) 477-8400

Professional Services in Environmental Management

- *Environmental Strategies*
- *Resources Planning*
- *Waste Management*
- *Hydrogeology*
- *Biology*
- *Water Quality*
- *Engineering Geology*
- *Spill Response*

December 23, 1987 GLL 87-575

Mr. J.G. Micak
Manager, Environmental Projects
Ontario Waste Management Corporation
2 Bloor Street West
11th Floor
Toronto, Ontario
M4W 3E2

Attention: Mr. R. Szudy
Supervisor, Environmental Projects

Dear Sirs:

Re: Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Ground Water Management Strategies

We are pleased to provide you with our above noted report. This report is one of six Phase 4B companion reports describing baseline conditions, hydrogeologic inputs to landfill design, geotechnical inputs to facilities design, potential impacts of the landfill on ground water, potential impacts of the central operating area on ground water and ground water management strategies.

We thank you for this opportunity to be of service. Should you have any questions please do not hesitate to call.

Yours very truly,

GARTNER LEE LIMITED

E.G. Anderson, P.Eng.,
Consulting Hydrogeologist,
Project Director

G.W. Reynolds, M.Sc.,
Senior Hydrogeologist,
Project Manager

GWR:emh

TABLE OF CONTENTS

1.0 INTRODUCTION	1
1.1 BACKGROUND	1
1.2 PURPOSE AND SCOPE	4
1.3 OBJECTIVES	4
1.4 MONITORING PHILOSOPHY AND APPROACH	6
1.5 REPORT FORMAT	11
2.0 PRE-FACILITY (BASELINE) MONITORING	12
2.1 INTRODUCTION	12
2.2 PAST AND PRESENT MONITORING PROGRAM	12
2.2.1 Past Monitoring Program	12
2.2.2 Present Monitoring Program	12
2.2.3 Water Well Sampling	19
2.2.4 Continued Baseline Monitoring	19
3.0 OVERALL FACILITY	24
3.1 INTRODUCTION	24
3.2 POTENTIAL CONTAMINANT SOURCES	27
3.3 PATHWAY MONITORING	28
3.3.1 Ground Water Flow	31
3.3.2 Ground Water Quality	32
3.4 RECEPTORS	39
3.5 MITIGATION AND CONTINGENCY STRATEGIES	40
3.5.1 Mitigation Strategies	40
3.5.2 Contingency Strategies	41
3.6 DECOMMISSIONING STRATEGIES	44
3.7 END LAND USE	44
4.0 CENTRAL OPERATING AREA	45
4.1 INTRODUCTION	45
4.2 SOURCE MONITORING	46
4.2.1 Contaminants Characteristics	46
4.2.2 Performance Monitoring of Engineered Containment Devices	47

4.3 PATHWAY MONITORING 48
4.3.1 Ground Water Flow 48
4.3.2 Ground Water Quality 49
4.4 MITIGATION AND CONTINGENCY STRATEGIES 51
4.4.1 Mitigation Strategies 51
4.4.2 Contingency Strategies 51
4.5 DECOMMISSIONING STRATEGIES 51

5.0 LANDFILL 53
5.1 INTRODUCTION 53
5.2 OVERVIEW OF THE LANDFILL DESIGN AND OPERATIONS 53
5.3 SOURCE MONITORING 54
5.3.1 Leachate Quality 54
5.3.2 Ground Water Flow 59
5.4 PATHWAY MONITORING 62
5.4.1 Ground Water Flow 62
5.4.2 Ground Water Quality 62
5.5 MITIGATION AND CONTINGENCY STRATEGIES 66
5.5.1 Mitigation 66
5.5.2 Contingencies 66
5.6 DECOMMISSIONING AND END LAND USE 67

6.0 REFERENCES 69

LIST OF FIGURES

FIGURE 1-1 PREFERRED SITE 2

FIGURE 1-2 FACILITIES DEVELOPMENT PROCESS 3

FIGURE 1-3 PHASE 4B IMPACT ASSESSMENT APPROACH 5

FIGURE 1-4 SOURCE, PATHWAY RECEPTOR DIAGRAM 7

FIGURE 1-5 SCHEMATIC DIAGRAM OF GROUND WATER CONTAMINANT SOURCES, PATHWAYS, RECEPTORS, MONITORING BACK POCKET

FIGURE 1-6 GROUND WATER MONITORING, MITIGATION AND CONTINGENCY IMPLEMENTATION 10

FIGURE 2-1 GROUND WATER LEVEL MONITORING LOCATIONS (1985/86 AND 87/88) 14

FIGURE 2-2 GROUND WATER SAMPLING LOCATIONS (1985/86) 16

FIGURE 2-3 GROUND WATER SAMPLING LOCATIONS (1987/88) 18

FIGURE 2-4 WATER SUPPLIES SAMPLED BY MOE (MAY, 1987) 22

FIGURE 3-1 PLAN VIEW OF PROPOSED OWMC FACILITY 25

FIGURE 3-2 SCHEMATIC CROSS-SECTION THROUGH LANDFILL 26

FIGURE 3-3 SHALLOW GROUND WATER MONITORING LOCATIONS - OVERALL FACILITY MONITORING 34

FIGURE 3-4 EXAMPLE CONSTRUCTION TECNIQUES FOR SHALLOW GROUND WATER MONITORS IN WEATHERED OVERBURDEN SOILS 35

FIGURE 3-5 BEDROCK GROUND WATER MONITORING LOCATIONS - OVERALL FACILITY MONITORING 38

FIGURE 3-6 CONSTRUCTION AND OPERATION OF AN INTERCEPTOR TRENCH IN THE WEATHERED SILT AND CLAY 42

FIGURE 3-7 CONSTRUCTION AND OPERATION OF PURGE WELLS IN THE BEDROCK AQUIFER 43

FIGURE 4-1 GENERAL APPROACH TO DECOMMISSIOING 52

LIST OF TABLES

TABLE 2-1 1985/86 GROUND WATER FLOW AND QUALITY MONITORING PROGRAM 13

TABLE 2-2 PARAMETERS ANALYZED FOR DETAILED INORGANIC AND GENERAL CHEMISTRY (85/86 PROGRAM) 15

TABLE 2-3 1987/88 GROUND WATER FLOW & QUALITY MONITOR PROGRAM 17

TABLE 2-4 PARAMETERS ANALYZED FOR 1987/88 WATER QUALITY PROGRAM 20

TABLE 3-1 OVERALL FACILITIES PATHWAY MONITORING 29

TABLE 5-1 LEACHATE QUALITY MONITORING - LABORATORY LEACHING TESTS 55

TABLE 5-2 LEACHATE QUALITY MONITORING - LEACHATE SAMPLING WITHIN THE LANDFILL 56

TABLE 5-3 PERFORMANCE MONITORING OF LANDFILL - GROUND WATER FLOW 60

TABLE 5-4 PERFORMANCE MONITORING OF LANDFILL - GROUND WATER QUALITY 63

LIST OF APPENDICES

APPENDIX A	MITIGATION OF ABANDONED BOREHOLES, GROUND WATER MONITORS AND WATER WELLS
APPENDIX B	ONTARIO WATER RESOURCES ACT SECTION 21
APPENDIX C	MOE RECOMMENDED METHODS FOR PLUGGING ABANDONED WATER WELLS
APPENDIX D	U.S. EPA PROTOCOLS FOR GROUTING AND WELL ABANDONMENT
APPENDIX E	MONITOR/BOREHOLE DETAILS
APPENDIX F	REPORT FROM SCIENTIFIC WASTE STRATEGIES INC.

1.0 INTRODUCTION

1.1 BACKGROUND

This Report documents a portion of the geoscience studies (which incorporates geology, hydrogeology, and geotechnics) carried out as part of Phase 4B of the Ontario Waste Management Corporation's (OWMC) Facilities Development Process. Phase 4B involves detailed assessments of the Preferred Site and surrounding area based on several disciplines, including the geosciences. The Preferred Site and immediate vicinity are illustrated in Figure 1-1.

The specific objectives of Phase 4B are to:

1. Define the existing environmental conditions (baseline) of the preferred siting option,

2. Predict and assess potential risks and impacts that may be associated with the proposed facility design and operations,

3. Identify and develop appropriate mitigative measures to minimize the potential risks and impacts,

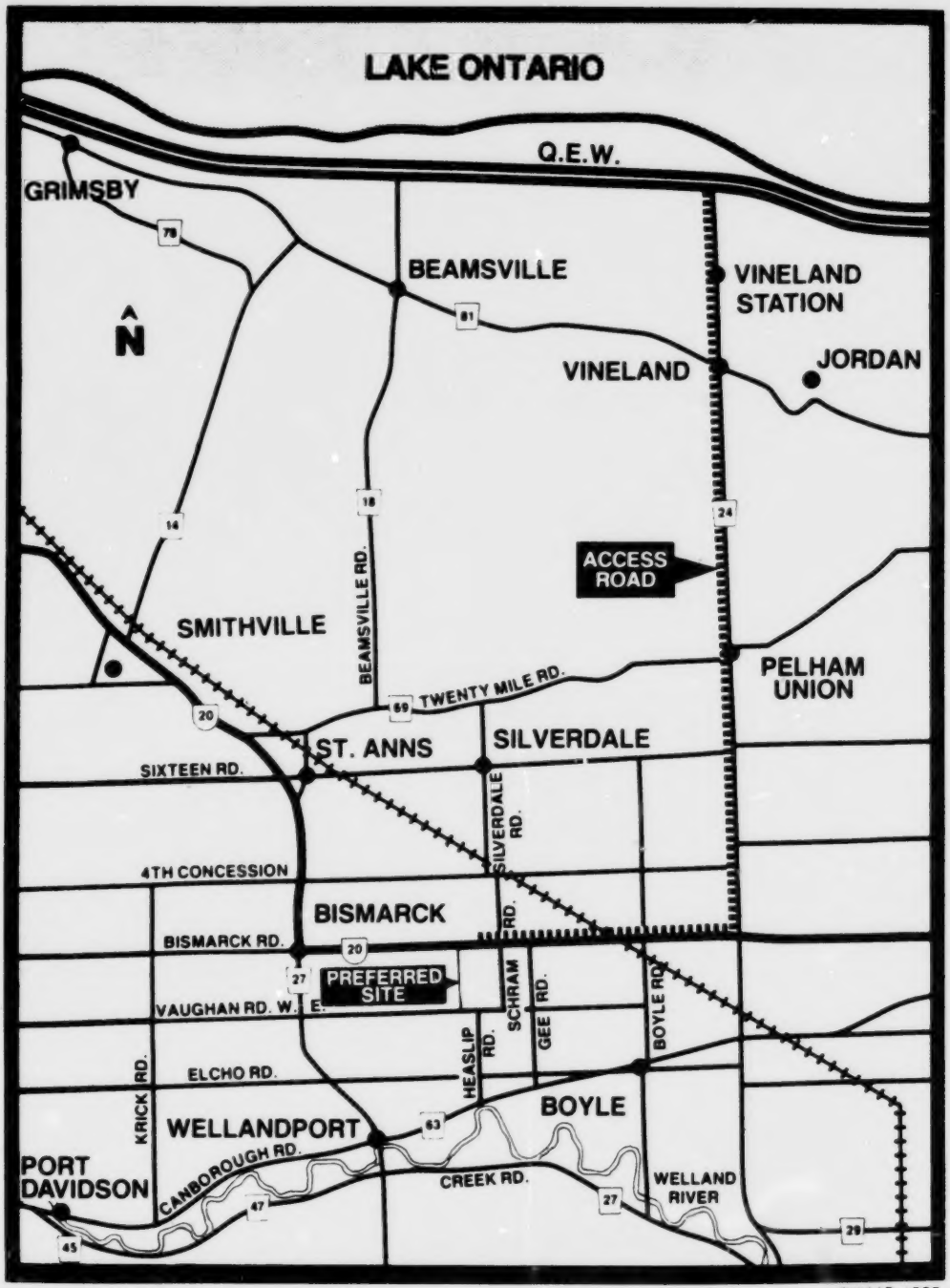
4. Predict and assess residual risks and impacts after mitigation,

5. Identify and develop monitoring and contingency programs that will be implemented to assess the effectiveness of the design and operations in minimizing risks and impacts, and

6. Prepare documentation to meet the requirements of Ontario's Environmental Assessment Act.

Figure 1-2 illustrates how Phase 4B relates to the other Phases of the OWMC Site Assessment and Facilities Development Process. For the

Township of West Lincoln, Regional Municipality of Niagara. Local Detail.

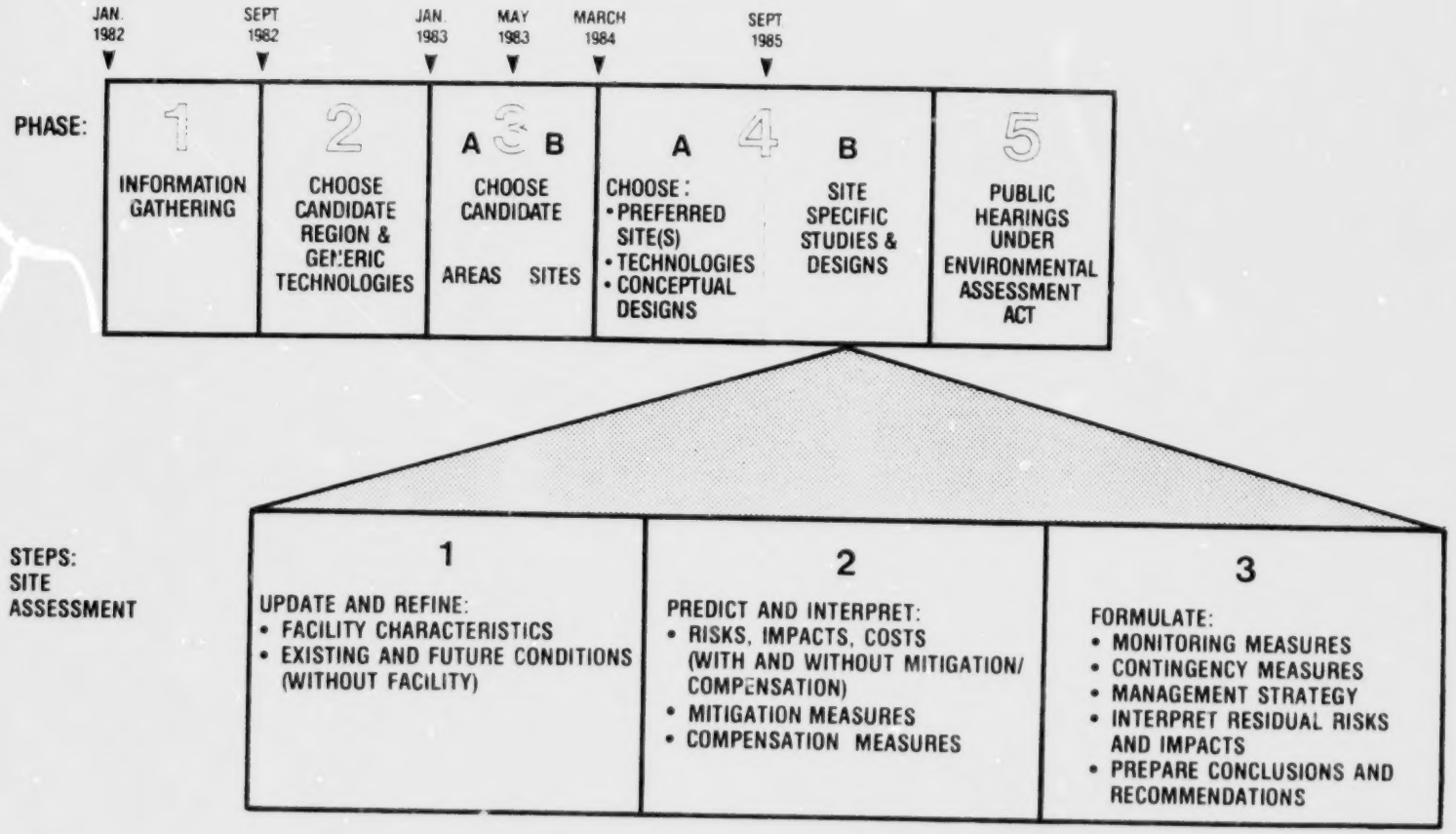


Ontario Waste Management Corporation

Gartner Lee Limited

Preferred Site

Figure 1.1



OWMC Ontario Waste Management Corporation

Gartner Lee Limited

FACILITIES DEVELOPMENT PROCESS

Figure 1.2

geosciences, Gartner Lee Limited's (GLL) Phase 4B studies have focused on:

1. Establishing baseline conditions for the Preferred Site (GLL 1987a),

2. Providing required input to OWMC's engineering consultants for conceptual facilities design (GLL 1987b; 1987c),

3. Assessing potential ground water impacts from the Central Operating Area, (GLL 1987e),

4. Assessing, mitigating and comparing various engineered landfill design concepts as input to OWMC's selection of the shallow entombed landfill (GLL 1987b),

5. Assessing potential ground water impacts from the shallow entombed landfill (GLL 1987d), and

6. Developing an overall ground water management plan through monitoring, mitigation and contingency strategies (this Report).

1.2 PURPOSE AND SCOPE

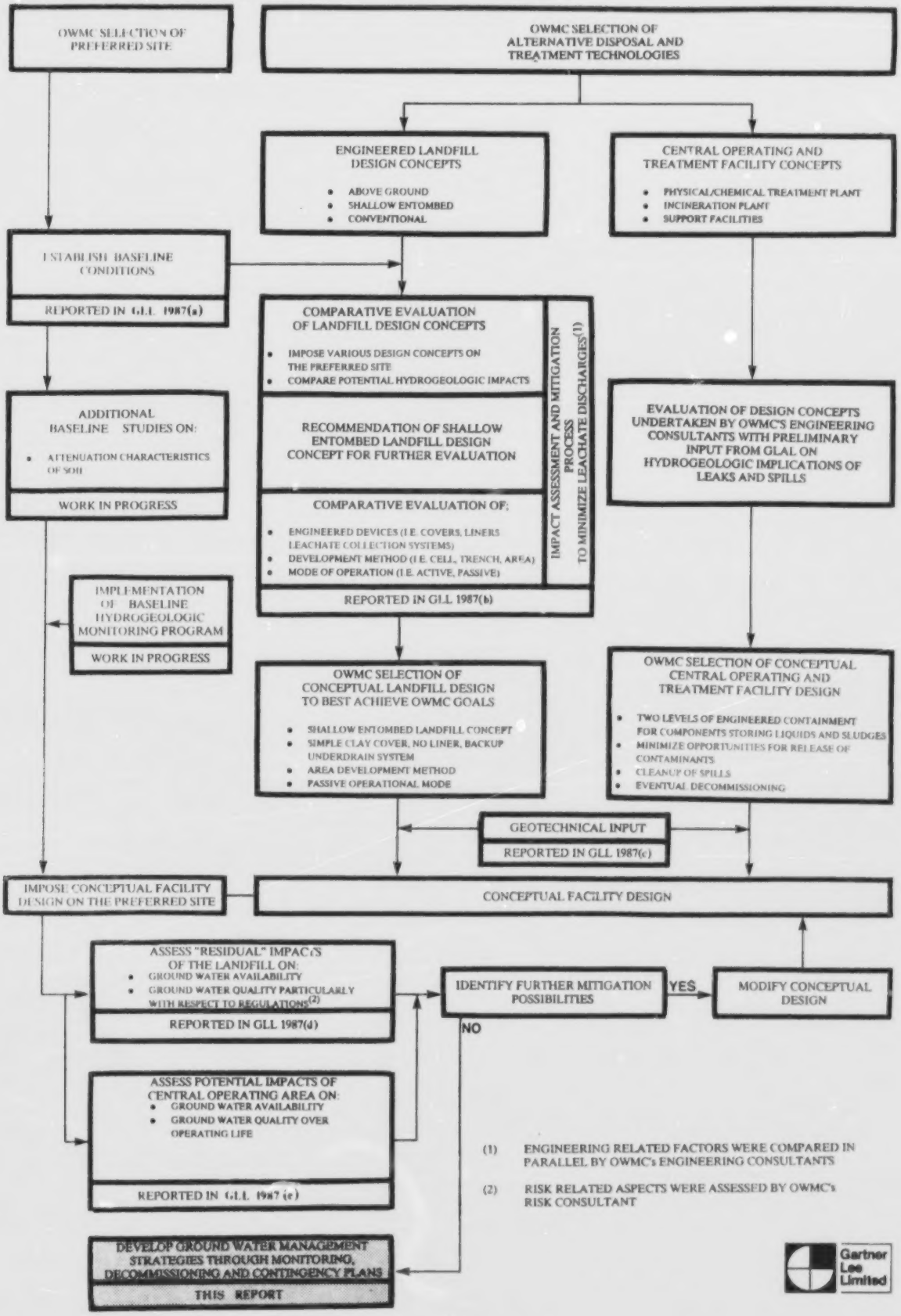
This Report outlines the overall ground water management plan through development of monitoring, mitigation and contingency plans. Figure 1-3 illustrates how this Report fits into GLL's Phase 4B studies.

Detailed protocols for ground water monitor installation techniques and sampling techniques are not included in this report. These would be developed at the detailed design stage following approval in principle of the Facility.

1.3 OBJECTIVES

Ground water monitoring is an integral part of all waste management facilities. The potential release of contaminants which could represent a health and/or environmental concern, necessitates the surveillance of the surrounding environment.

FIGURE 1-3
PHASE 4B: IMPACT ASSESSMENT APPROACH: Geoscience


OWMC SELECTION OF PREFERRED SITE
OWMC SELECTION OF ALTERNATIVE DISPOSAL AND TREATMENT TECHNOLOGIES
ENGINEERED LANDFILL DESIGN CONCEPTS
• ABOVE GROUND
• SHALLOW ENTOMBED
• CONVENTIONAL
CENTRAL OPERATING AND TREATMENT FACILITY CONCEPTS
• PHYSICAL/CHEMICAL TREATMENT PLANT
• INCINERATION PLANT
• SUPPORT FACILITIES
ESTABLISH BASELINE CONDITIONS
REPORTED IN GLL 1987(a)
COMPARATIVE EVALUATION OF LANDFILL DESIGN CONCEPTS
• IMPOSE VARIOUS DESIGN CONCEPTS ON THE PREFERRED SITE
• COMPARE POTENTIAL HYDROGEOLOGIC IMPACTS
RECOMMENDATION OF SHALLOW ENTOMBED LANDFILL DESIGN CONCEPT FOR FURTHER EVALUATION
COMPARATIVE EVALUATION OF;
• ENGINEERED DEVICES (I.E. COVERS, LINERS LEACHATE COLLECTION SYSTEMS)
• DEVELOPMENT METHOD (I.E. CELL, TRENCH, AREA)
• MODE OF OPERATION (I.E. ACTIVE, PASSIVE)
IMPACT ASSESSMENT AND MITIGATION PROCESS TO MINIMIZE LEACHATE DISCHARGES(1)
REPORTED IN GLL 1987(b)
EVALUATION OF DESIGN CONCEPTS UNDERTAKEN BY OWMC'S ENGINEERING CONSULTANTS WITH PRELIMINARY INPUT FROM GLAL ON HYDROGEOLOGIC IMPLICATIONS OF LEAKS AND SPILLS
ADDITIONAL BASELINE STUDIES ON:
• ATTENUATION CHARACTERISTICS OF SOIL
WORK IN PROGRESS
IMPLEMENTATION OF BASELINE HYDROGEOLOGIC MONITORING PROGRAM
WORK IN PROGRESS
OWMC SELECTION OF CONCEPTUAL LANDFILL DESIGN TO BEST ACHIEVE OWMC GOALS
• SHALLOW ENTOMBED LANDFILL CONCEPT
• SIMPLE CLAY COVER, NO LINER, BACKUP UNDERDRAIN SYSTEM
• AREA DEVELOPMENT METHOD
• PASSIVE OPERATIONAL MODE
OWMC SELECTION OF CONCEPTUAL CENTRAL OPERATING AND TREATMENT FACILITY DESIGN
• TWO LEVELS OF ENGINEERED CONTAINMENT FOR COMPONENTS STORING LIQUIDS AND SLUDGES
• MINIMIZE OPPORTUNITIES FOR RELEASE OF CONTAMINANTS
• CLEANUP OF SPILLS
• EVENTUAL DECOMMISSIONING
GEOTECHNICAL INPUT
REPORTED IN GLL 1987(c)
IMPOSE CONCEPTUAL FACILITY DESIGN ON THE PREFERRED SITE
CONCEPTUAL FACILITY DESIGN
ASSESS "RESIDUAL" IMPACTS OF THE LANDFILL ON:
• GROUND WATER AVAILABILITY
• GROUND WATER QUALITY PARTICULARLY WITH RESPECT TO REGULATIONS(2)
REPORTED IN GLL 1987(d)
IDENTIFY FURTHER MITIGATION POSSIBILITIES
YES
MODIFY CONCEPTUAL DESIGN
NO
ASSESS POTENTIAL IMPACTS OF CENTRAL OPERATING AREA ON:
• GROUND WATER AVAILABILITY
• GROUND WATER QUALITY OVER OPERATING LIFE
REPORTED IN GLL 1987 (e)
DEVELOP GROUND WATER MANAGEMENT STRATEGIES THROUGH MONITORING, DECOMMISSIONING AND CONTINGENCY PLANS
THIS REPORT
(1) ENGINEERING RELATED FACTORS WERE COMPARED IN PARALLEL BY OWMC's ENGINEERING CONSULTANTS
(2) RISK RELATED ASPECTS WERE ASSESSED BY OWMC's RISK CONSULTANT
Gartner Lee Limited

The main objectives of the ground water monitoring program are:

1) to establish a comprehensive pre-facility baseline description of the site's physical hydrogeologic and hydrogeochemical setting that will serve as a basis for comparison during facility construction and operation and after closure,

2) to check and refine predictions of potential facility impacts on ground water resource availability and quality,

3) to assess the performance of engineering components and safeguards built into the facilities,

4) to provide early warning of potential problems such that mitigative measures can be implemented or contingency plans activated prior to significant ground water resource impairment, and

5) to satisfy regulatory requirements.

1.4 MONITORING PHILOSOPHY AND APPROACH

The monitoring program described in this report is based on three major components that are common to all waste management facilities. These are:

1) the Source,
2) the Pathway, and
3) the Receptor.

Figure 1-4 shows the relationship between these components.

The Source of contaminants at the OWMC facility is characterized by the distinctly different nature of the operations at the landfill and the central operating area. Contaminants from the landfill are the result of ground water infiltration leaching soluble constituents from the solidified residues which are the solid byproducts of the

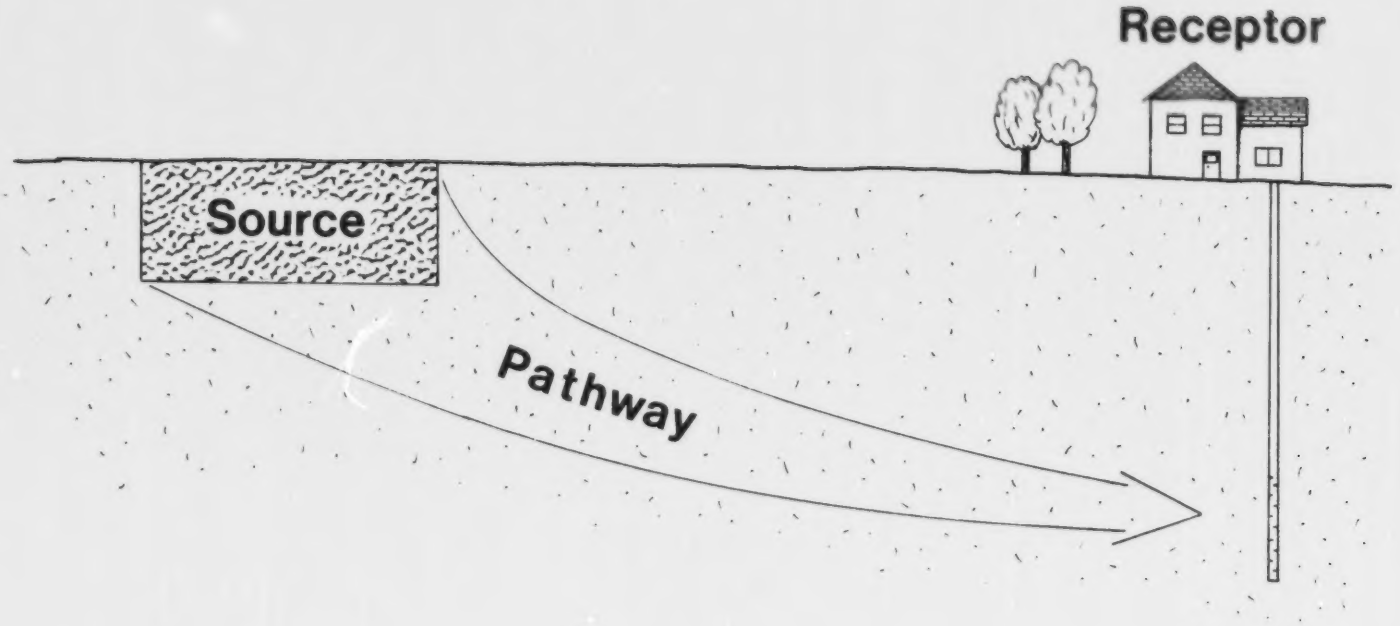


FIGURE 1-4
Source, Pathway, Receptor Diagram

various treatment processes in the central operating area. This slow leaching process will continue for hundreds of years. The reader is referred to the report entitled "Site Assessment - Phase 4B: Geology, Hydrogeology and Geotechnics; "Potential Impacts on Ground Water from the Landfill" (GLL 1987d) for a description of the landfill leachate characteristics.

Contaminants from the central operating area are distinctly different from the landfill in both their physical and chemical characteristics and the length of time that they will be present in the environment. Unlike the landfill, untreated wastes and additives and regeants will be handled in the central operating area. Although they are not intentionally placed in contact with the geologic materials, it is assumed that leaks and spills of untreated wastes may occur during the operational life of the site (assumed to be 50 years±). Any obvious spills or leaks would be remediated as they occur and any undetected leaks would be mitigated as part of the overall post-operational site decommissioning. For a further description of the plant emissions the reader is referred to the report entitled "Site Assessment - Phase 4B: Geology, Hydrogeology and Geotechnics; "Potential Impacts on Ground Water from the Central Operating Area" (GLL 1987e).

The Pathways for contaminant movement in the hydrogeologic environment at the Preferred Site are fully described in the Gartner Lee Limited baseline conditions report (GLL 1987a). The landfill and central operating area sources were superimposed onto the Preferred Site and contaminant migration through the various ground water pathways was described in the landfill impact assessment report (GLL 1987d) and the central operating area impact assessment report (GLL 1987e). The pathways described in these reports at this site consist of potential movement laterally through the upper more active shallow ground water flow system associated with the weathered silt and clay, vertically downwards through exploratory drill holes or water wells and by very slow ground water flow and diffusion downwards through the unweathered silt and clay.

An inventory of ground water use in the site area is contained in the baseline report (GLL 1987a). The potential Receptors at this site are those using the deep bedrock aquifer as a source of water supply, and those using the shallow ground water in the

weathered clay to replenish cistern supplies or as a limited supply of ground water to shallow large diameter wells. These receptors are humans and livestock.

There is also a pathway link with ground water to surface water in the shallow flow system associated with the upper fractured clays. This shallow ground water discharges to local drainage ditches and swales seasonally that could serve as a pathway to surface water receptors. The reader is referred to the report entitled "Site Assessment - Phase 4B: Surface Water" (M.M. Dillon, 1987) for a description of potential impacts on surface water resources and monitoring and contingency plans.

The detailed interrelationships amongst these three major components, the sources, pathways and receptors, is illustrated in Figure 1-5 contained in the sleeve at the back of this report. As summarized in Figure 1-6, monitoring of these three major components will be the focus of the ground water monitoring program.

The intent of the ground water management program is to monitor intensely, during initial years: (1) the performance of engineering devices to contain contaminants; (2) the physical and chemical characteristics of the source contaminants and; (3) how these contaminants will move along the hydrogeologic pathways. Less frequent but routine monitoring of potential receptors will be undertaken during this intensive initial monitoring program. However, the overall monitoring program emphasizes detection of potential impacts on-site to provide ample lead time to implement remedial or contingency measures to prevent receptor impact. Routine monitoring results for the source, pathways and receptors are to be compared to predicted impacts. If actual data from the monitoring confirms predictions and OWMC and Ministry of the Environment (MOE) performance criteria are being met, then routine monitoring would continue with calibration of the predictive model to enhance understanding of the site performance. The need for long term monitoring would be assessed based on the results of the performance monitoring. However, if comparison with predictions, and OWMC and MOE performance criteria was not acceptable then the monitoring program is designed to trigger the activation of mitigative or contingency measures. Mitigation could consist of design or operaitons changes during the operating life of the site and immediate clean-up of spills or leaks. Contingency plans are plans that could

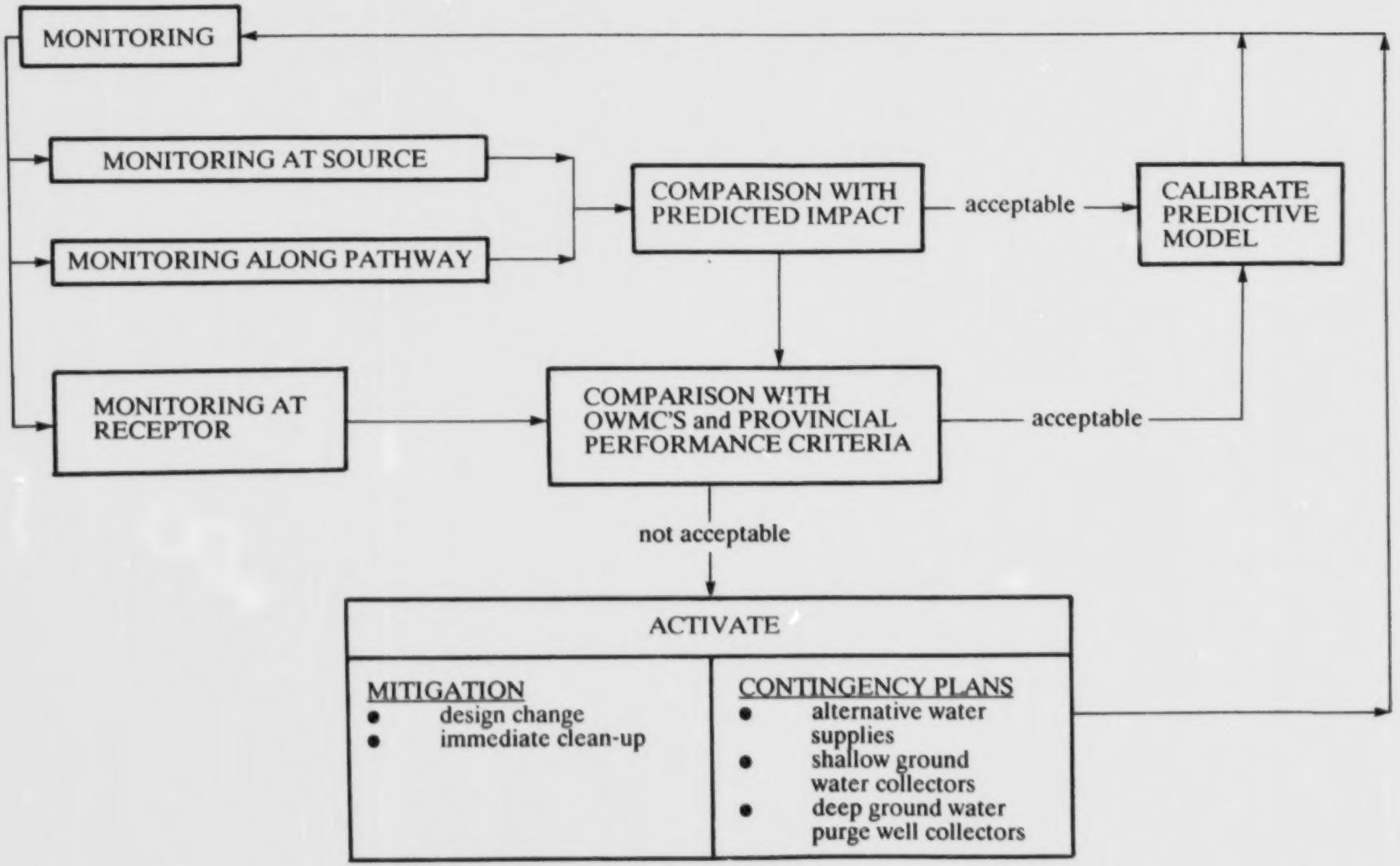


FIGURE 1-6

GROUND WATER MONITORING, MITIGATION AND CONTINGENCY IMPLEMENTATION

Gartner Lee Limited

be implemented for conceivable events however unlikely they may be. Contingency measures could consist of providing an alternate water supply or interception of contaminated ground water by shallow drains or deep purge wells as examples.

1.5 REPORT FORMAT

The remainder of this report is organized as follows:

Chapter 2 - description of the monitoring program to establish the baseline conditions both on and off-site

Chapter 3 - description of overall facility monitoring, mitigation, contingencies, decommissioning strategies and end land use that are common for both the landfill and the central operating area.

Chapter 4 - description of monitoring, mitigation, contingencies, decommissioning strategies and end land use that are unique to the central operating area.

Chapter 5 - description of monitoring, mitigation, contingencies, decommissioning strategies and end land use that are unique to the landfill.

2.0 PRE-FACILITY (BASELINE) MONITORING

2.1 INTRODUCTION

Baseline monitoring establishes the pre-facility conditions to which future monitoring during and after operations can be compared to assess if impacts are occurring.

Baseline monitoring of ground water flow and ground water quality has been on-going at the Preferred Site since the fall of 1985 when Phase 4B studies were initiated on-site. This Chapter describes the past and present baseline monitoring programs and discusses the scope of future baseline monitoring programs.

2.2 PAST AND PRESENT MONITORING PROGRAM

2.2.1 Past Monitoring Program

Ground water flow and quality monitoring was conducted over the period November 1985 to October 1986 as part of the detailed assessment of geologic, hydrogeologic and geotechnical baseline conditions. This monitoring program and the results are described in detail in the report entitled "Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics, Baseline Conditions" (GLL, 1987a). Table 2-1 summarizes the 85-86 monitoring program.

The ground water quality monitors installed and the parameters analyzed for the 85-86 program were intended only to assist in the interpretation of the ground water flow regime and therefore were not intended to establish comprehensive baseline ground water quality. Hence the emphasis on inorganic and isotopic constituents, with only one analysis for toxic organic contaminants.

2.2.2 Present Monitoring Program

A baseline ground water flow and quality monitoring program is presently on-going covering the period June, 1987 to June, 1988. The elements of this program are summarized in Table 2-3.

Note that the list of parameters being analyzed has been expanded to include all parameters listed in the Ontario Drinking Water Objectives plus organic contaminants

TABLE 2-1: 1985/86 GROUND WATER FLOW AND QUALITY MONITORING PROGRAM

GROUND WATER FLOW

- installation of a total of 91 water level monitors at 12 on-site and 4 off-site locations (includes 14 pneumatic piezometers, 16 standpipes and 61 standard piezometers) (Figure 2-1),

- hydraulic testing included:
  - 65 slug tests (in-situ hydraulic conductivity testing)
  - 20 packer tests at two sites (in-situ hydraulic conductivity testing of rock)
  - 17 laboratory tests of vertical and horizontal hydraulic conductivity of overburden, and
  - 1 pump test in rock,

- water level monitoring in all monitors every few days from November, 1985 until February, 1986 or until near equilibrium water levels achieved - monthly water level monitoring after February 1986.

GROUND WATER QUALITY

- 36 monitors sampled twice for detailed inorganic and general chemistry (see Table 2-2 for parameters and Figure 2-2 for locations),

- one bedrock monitor sampled for a scan of organic parameters on the U.S. Environmental Protection Agency's priority pollutant list,

- 36 monitors sampled once for oxygen-18 and deuterium isotopes, plus a second sampling of the five bedrock monitors,

- 36 monitors sampled at least once for direct counting of tritium; 18 monitors (5 bedrock, 13 overburden) sampled once for enriched counting of tritium; and, 4 selected overburden monitors sampled for enriched counting of very low level tritium activity,

- soil samples from a variety of depths at two locations were collected for pore water squeezing and analysis of the pore water for chloride and the isotopes oxygen-18 and deuterium.

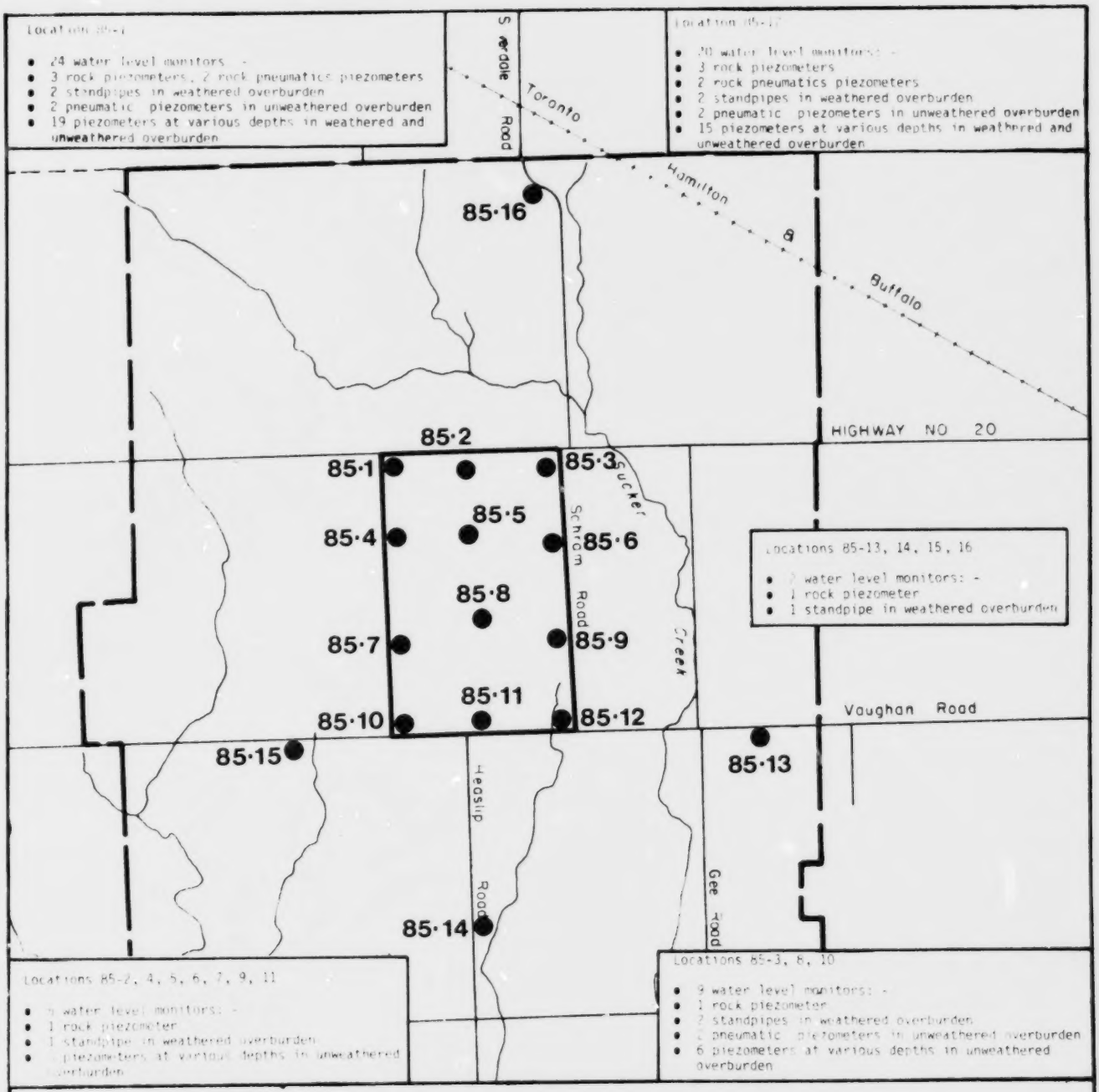


Figure 2·1
GROUND WATER LEVEL MONITORING LOCATIONS (1985/86 and 87/88)

—— Boundary of Preferred Site

● Monitoring Location

TABLE 2-2: PARAMETERS ANALYZED FOR DETAILED INORGANIC AND GENERAL CHEMISTRY (85/86 PROGRAM)

1. **GENERAL CHEMISTRY AND MAJOR IONS**

pH (field), temperature (field), electrical conductivity (field), total dissolved solids, dissolved inorganic carbon, dissolved organic carbon, alkalinity, calcium, potassium, magnesium, sodium, silicon, strontium, fluoride, chloride and sulphate.

2. **MINOR IONS**

silver, aluminum, boron, barium, beryllium, cadmium, cobalt, chromium, copper, iron, manganese, molybdenum, nickel, phosphorus, lead, thorium, titanium, vanadium, zinc, zirconium, bromine, nitrite, nitrate, phosphate and sulphide.

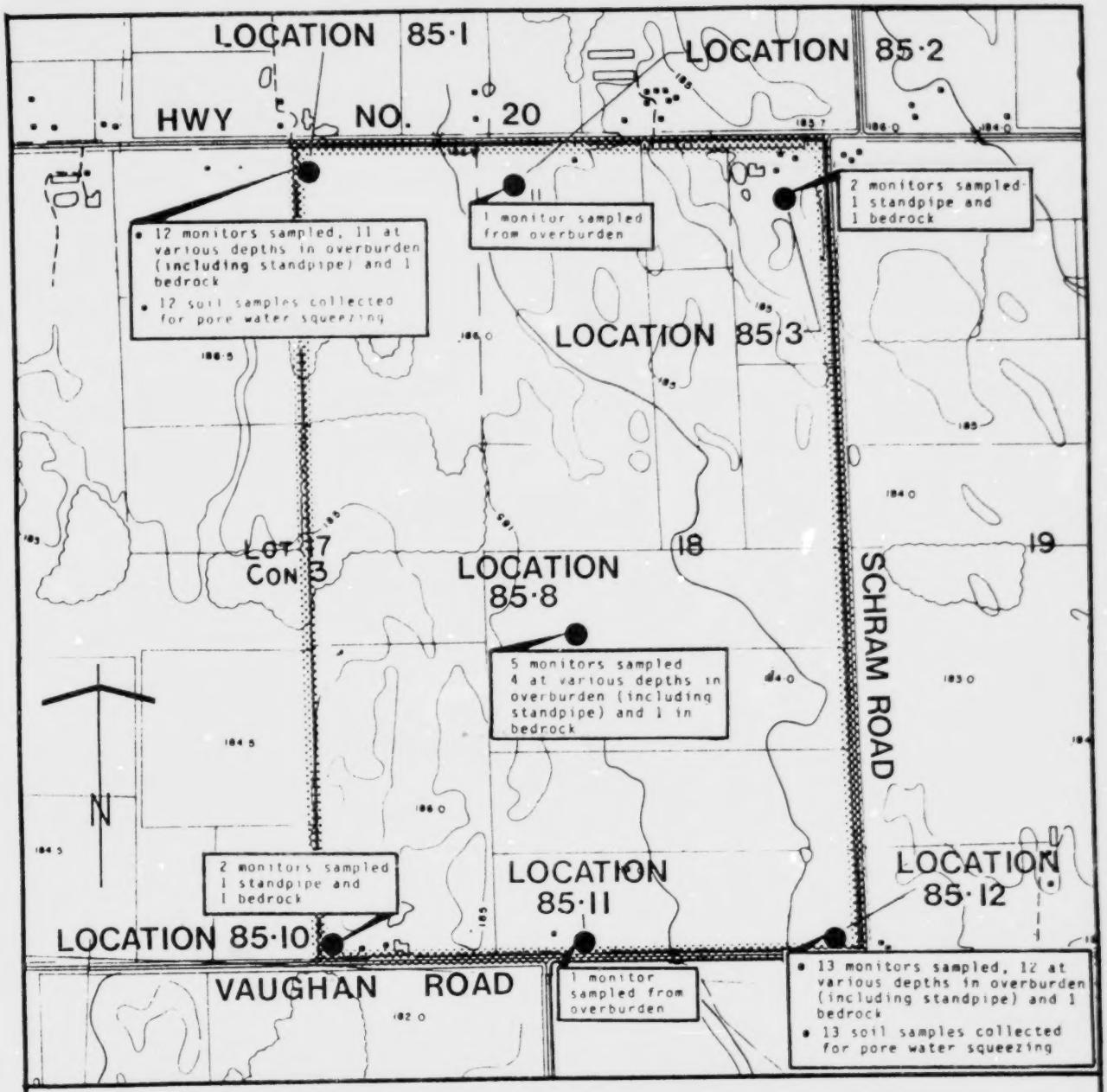

LOCATION 85·1
LOCATION 85·2
HWY NO. 20
• 12 monitors sampled, 11 at various depths in overburden (including standpipe) and 1 bedrock
• 12 soil samples collected for pore water squeezing
1 monitor sampled from overburden
2 monitors sampled 1 standpipe and 1 bedrock
LOCATION 85·3
LOT 17
CON 3
18
19
LOCATION 85·8
SCHRAM ROAD
5 monitors sampled 4 at various depths in overburden (including standpipe) and 1 in bedrock
N
2 monitors sampled 1 standpipe and 1 bedrock
LOCATION 85·10
LOCATION 85·11
LOCATION 85·12
VAUGHAN ROAD
1 monitor sampled from overburden
• 13 monitors sampled, 12 at various depths in overburden (including standpipe) and 1 bedrock
• 13 soil samples collected for pore water squeezing

Figure 2·2
GROUND WATER SAMPLING LOCATIONS (1985/86)

Boundary of Preferred Site

Sampling Location

0 500 metres

SCALE

Gartner Lee Limited

TABLE 2-3 : 1987/88 GROUND WATER FLOW & QUALITY MONITOR PROGRAM

A. GROUND WATER FLOW

- Measurement of water levels in all monitors once every 4 months
- Detailed monitoring of water levels in all monitors at location 85-1. Frequency is once a week unless rainfall event; then 2 days after a one day event, or once during and once 2 days after a long event (week of recordable precipitation)

Notes : - see Figure 2-1 for water level monitoring locations

B. GROUND WATER QUALITY

MONITOR SAMPLED	HYDROSTRATI-GRAPHIC UNIT	MAJOR IONS	MINOR IONS	ISOTOPES O18 & H2	PESTICIDES & PCB's	PRIORITY POLLUTANTS	C14	TRITIUM
1-1	bedrock	x	x	x	x	x		
1-10	weathered	x	x		x	x		
1-25	unweathered						x	
1-26	unweathered						x	
2-4	unweathered	x	x		x	x		
3-1	bedrock	x	x	x			x	
3-10	weathered	x	x					
8-1	bedrock	x	x	x	x	x	x	
8-4	unweathered	x	x		x	x		
8-10	weathered	x	x		x	x		
10-1	bedrock	x	x	x				
10-10	weathered	x	x					
11-4	unweathered	x	x		x	x		
12-1	bedrock	x	x	x	x	x	x	
12-10	weathered	x	x		x	x		x
12-13	weathered							x
12-14	weathered							x
12-15	weathered							x
12-16	weathered							x
12-17	weathered							x
12-18	unweathered							x
12-19	unweathered							x
12-20	unweathered							x
12-21	unweathered							x
14-1	bedrock	x	x	x	x	x	x	
16-1	bedrock	x	x	x	x	x	x	

Notes: - see Table 2-4 for parameters analyzed in water quality program
- see Figure 2-3 for water quality sampling locations

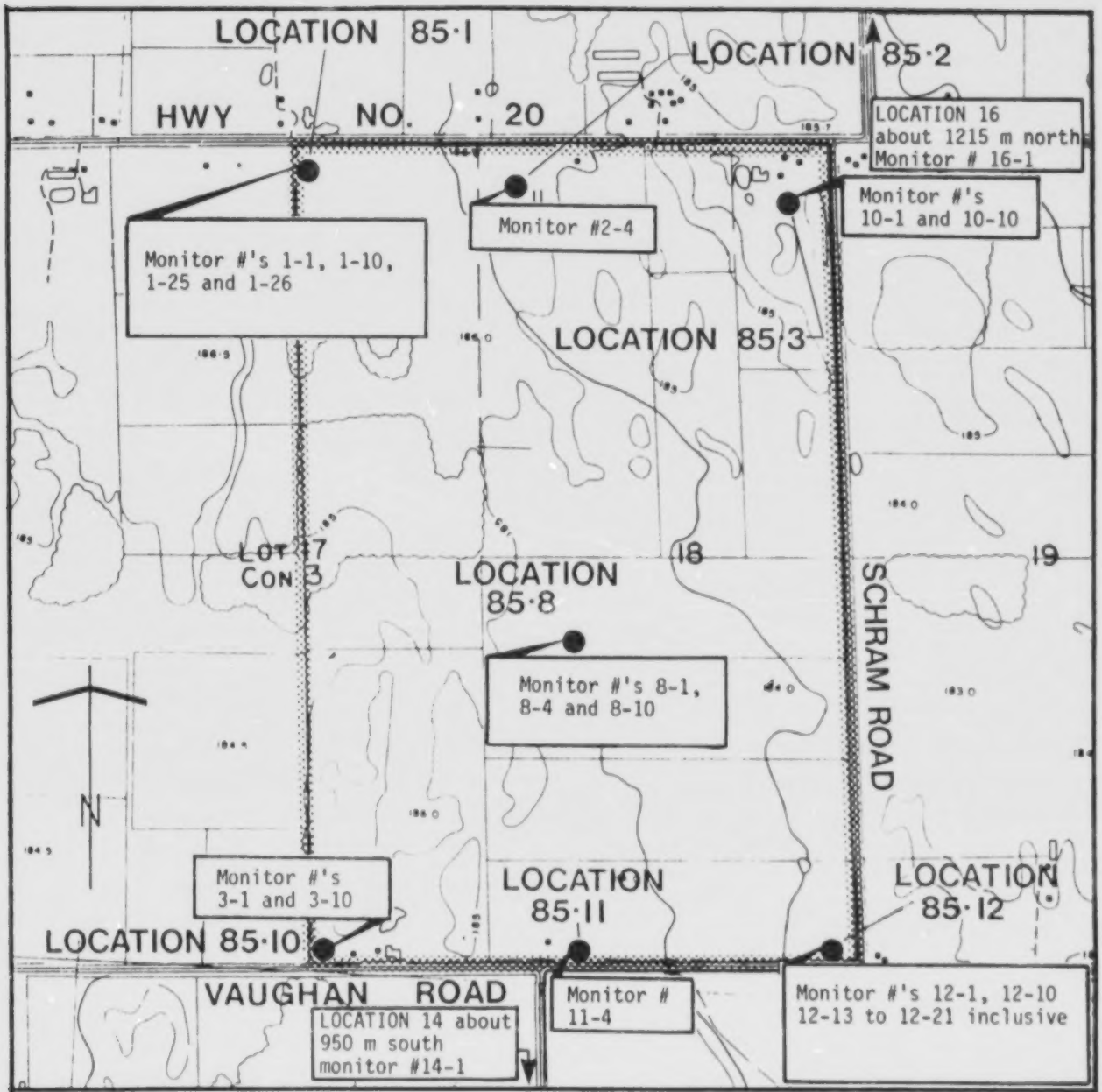


Figure 2·3
GROUND WATER SAMPLING LOCATIONS (1987/88)

Boundary of Preferred Site

Sampling Location

0 500 metres

SCALE

Gartner Lee Limited

from the U.S. Environmental Protection Agency's priority pollutant list (Table 2-4). Atrazine was also included in response to requests from local citizens.

2.2.3 Water Well Sampling

In early May, 1987 the Ministry of the Environment sampled and analyzed private water supplies in the vicinity of the Preferred Site. The nine sampling locations are shown on Figure 2-4. These included seven drilled wells into bedrock or the base of the overburden; one cistern; and one location where it is uncertain whether the cistern or the drilled well was sampled. Water samples were analyzed for conductivity, total hardness, calcium, magnesium, sodium, potassium, total alkalinity, pH, chloride, sulphate, total kjeldahl nitrogen, ammonium, nitrate, nitrite and total phenolics. The results of this water quality survey are available from the Ministry of the Environment, West Central Region, Hamilton, Ontario. Interpretation of this data will be included as part of the on-going baseline monitoring program, which will be reported upon in 1988.

2.2.4 Continued Baseline Monitoring

The period between conclusion of the present program (i.e. mid-1988), and site construction (pending approval) is anticipated to be a number of years. During this period baseline monitoring of ground water flow and quality should continue. This will provide invaluable data on long term variability that could not be repeated at a later date. The scope of the program is anticipated to be similar to the present one (Section 2.2.2), although this should be reviewed once the results of the present program have been assessed. The program should also be expanded to include all water wells in the site vicinity, since to date little or no baseline information is available for these wells. This will require the approval of property owners.

The monitoring program to assess facility performance will require ground water monitors in addition to the existing network (see subsequent sections). These monitors should be installed as soon as practical, following approval and before major construction so that baseline information can be established for these locations.

Surface and near surface soil samples should also be collected from the proposed Central Operating Area immediately following approval for complete inorganic and

TABLE 2-4 : PARAMETERS ANALYZED FOR 1987/88 WATER QUALITY PROGRAM

(1) MAJOR IONS -

Alkalinity	Potassium	pH
Calcium	Silicon	Temperature
Chloride	Sodium	Dissolved Inorganic Carbon
Fluoride	Strontium	Dissolved Organic Carbon
Magnesium	Sulphate	Total Dissolved Solids

(2) MINOR IONS -

Aluminum	Cyanide	Phosphorus
Ammonia	Iron	Selenium
Arsenic	Lead	Silver
Barium	Manganese	Sulfide
Beryllium	Mercury	Sulfur
Boron	Molybdenum	Titanium
Bromine	Nickel	Thorium
Cadmium	Nitrate	Vanadium
Chromium	Nitrite	Zinc
Cobalt	Phosphate	Zirconium
Copper		

(3) EPA ORGANIC PRIORITY POLLUTANTS

(3.1) PURGEABLES (EPA 624) -

Benzene	1,2-Dichlorobenzene	Ethylbenzene
Bromodichloromethane	1,3-Dichlorobenzene	Methylene Chloride
Bromoform	1,4-Dichlorobenzene	1,1,2,2-Tetrachloroethane
Bromomethane	Dichlorodifluoromethane	Tetrachloroethene
Carbon Tetrachloride	1,1-Dichloroethane	Toluene
Chlorobenzene	1,2-Dichloroethane	1,1,1-Trichloroethane
Chloroethane	1,1-Dichloroethene	1,1,2-Trichloroethane
2-Chlorethylvinyl ether	trans-1,2-Dichloroethene	Trichloroethene
Chloroform	1,2-Dichloropropane	Trichlorofluoromethane
Chloromethane	cis-1,2-Dichloropropene	Vinyl Chloride
Dibromochloromethane	trans-1,2-Dichloropropene	

(3.2) BASE/NEUTRAL EXTRACTABLES (EPA 625) -

Polynuclear Aromatic Hydrocarbons :	Phthalate Esters	Chlorinated Benzenes
	Butylbenzylphathalate	1,2-Dichlorobenzene
Acenaphthene	Di-n-butylphthalate	1,3-Dichlorobenzene
Acenaphthylene	Diethylphthalate	1,4-Dichlorobenzene
Anthracene	Dimethylphthalate	1,2,4-Trichlorobenzene
Benzo (a) anthracene	Di-n-octylphthalate	Hexachlorobenzene
Benzo (b) fluoranthene	bis-(2-ethylhexyl) phthalate	
Benzo (k) fluoranthene		Other Compounds
Benzo (ghi) perylene	Haloethers	
Benzo (a) pyrene		Benzidine
Chrysene	4-Bromophenylphenylether	2-Chloronaphthalene
Dibenzo (ah) anthracene	bis (2-Chloroethoxy) methane	3,3'-Dichlorobenzidine
Fluoranthene	bis (2-Chloroethyl) ether	2,4-Dinitrotoluene
Fluorene	bis (2-Chloroisopropyl) ether	2,6-Dinitrotoluene
Indeno (1,2,3,-cd) pyrene	4-Chlorophenylphenylether	Hexachlorobutadiene
Naphthalene	Nitrosamines	Hexachlorocyclopentadiene
Phenanthrene	N-nitrosodimethylamine	Hexachloroethane
Pyrene	N-nitrosodiphenylamine	Isophorone
	N-nitrosodi-n-propylamine	Nitrobenzene

EPA = U.S. Environmental Protection Agency

TABLE 2-4 : PARAMETERS ANALYZED FOR 1987/88 WATER QUALITY PROGRAM
(CONTINUE...)

(3.3) ACID EXTRACTABLES (EPA 625) -

4-Chloro-3-methylphenol	2,4-Dinitrophenol	Pentachlorophenol
2-Chlorophenol	2-Nitrophenol	Phenol
2,4-Dichlorophenol	4-Nitrophenol	2,3,6-Trichlorophenol
2,4-Dimethylphenol	2-Methyl-4,6-dinitrophenol	

(4) PESTICIDES/PCBs

(4.1) ORGANOCHLORINE PESTICIDES/PCBs (EPA 608) -

Aldrin	alpha-Endosulfan	PCB-1016
alpha-BHC	beta-Endosulfan	PCB-1221
beta-BHC	Endosulfan Sulphate	PCB-1242
gamma-BHC (Lindane)	Endrin	PCB-1248
delta-BHC	Endrin Aldehyde	PCB-1254
Chlordane	Heptachlor	PCB-1260
4,4'-DDD	Heptachlor Epoxide	Toxaphene
4,4'-DDT		

(4.2) O.D.W.O. PESTICIDES -

Atrazine	Diazinon	Parathion
Carbaryl	Methoxychlor	2,4-D
DDT	Methyl Parathion	2,4,5-TP
Dieldrin		

O.D.W.O. = Ontario Drinking Water Objectives

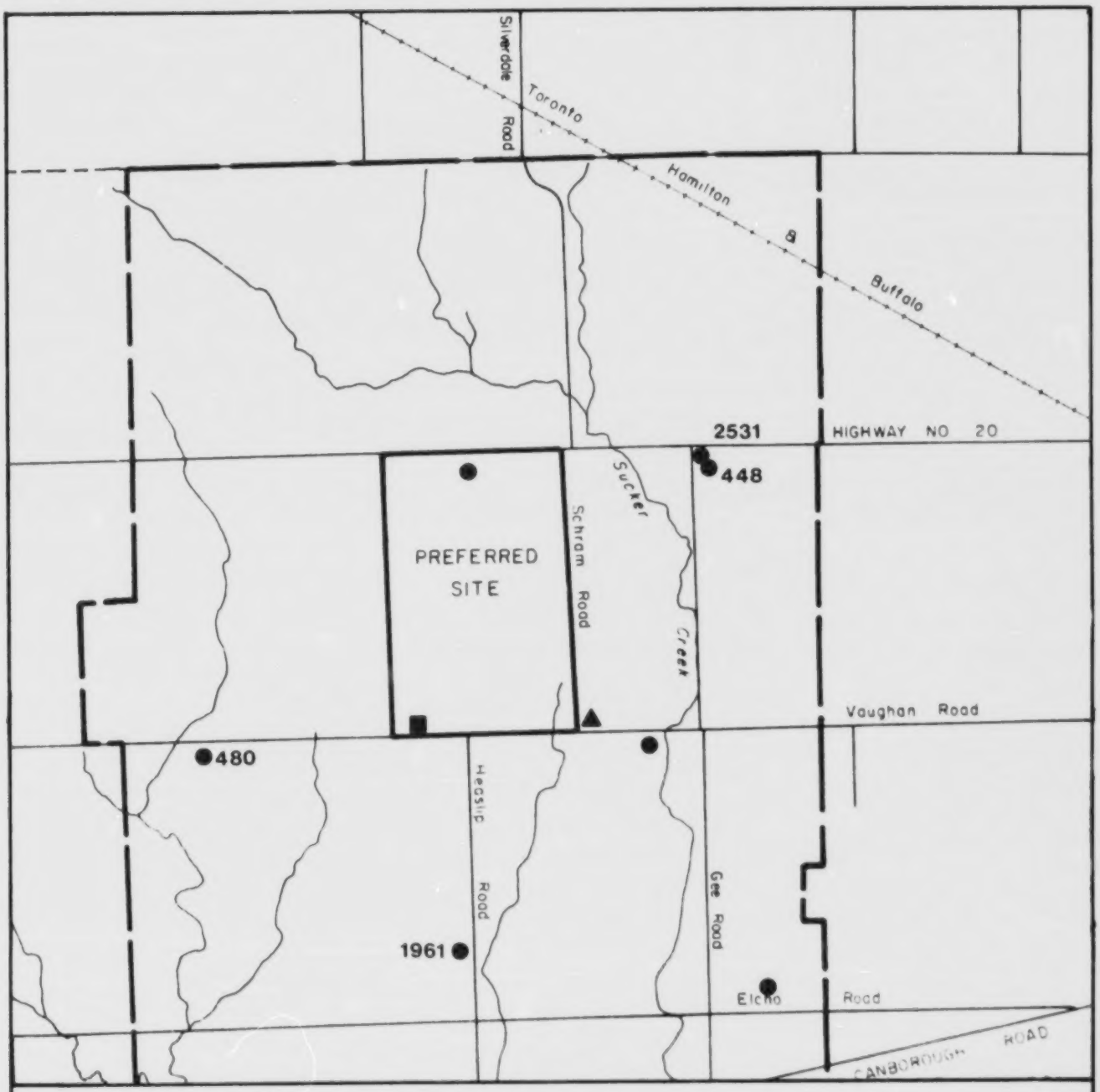


Figure 2·4
WATER SUPPLIES SAMPLED BY M.O.E. (May, 1987)

● Drilled Well Into Bedrock or Base Of Overburden

448 M.O.E Well Reference Number

▲ Cistern

■ Not Certain Whether Drilled Well Or Cistern Was Sampled At This Location

0 1000
metres

Gartner Lee Limited

organic chemical characterization. This will provide the baseline data for guiding future remediation of contaminated soils during operation and decommissioning.

3.0 OVERALL FACILITY

3.1 INTRODUCTION

In a general sense, the proposed OWMC Treatment and Disposal Facility can be divided into three major areas (Figure 3-1). These are:

- Central Operating Area (COA),
- landfill, and
- buffer zones (perimeter and internal)

Briefly, the centrally-located COA is the area of the facility where all incoming wastes are transferred, stored (interim), tested, and treated. As well, the COA contains all of the facilities for handling and storing treatment reagents and housing the administrative, maintenance, and operations staff.

The shallow entombed engineered landfill, which surrounds the COA on all sides, is the disposal area for the solidified residues produced in the COA from waste treatment. The design of the landfill is schematically illustrated in the cross section in Figure 3-2. Further details regarding the facility design and layout can be found in OWMC's "Design and Operations" report (Monenco, 1987).

There are two designated buffer zones on the site. The internal buffer zone is 30 m wide surround the COA. This zone provides for servicing of the landfill operation. The perimeter buffer zone is 50 m wide around the boundary of the site. This zone provides for major perimeter servicing, monitoring and screening.

The ground water management strategies associated with the COA and the landfill are unique and specific; therefore, separate chapters of this report are devoted to these topics (Chapter 4.0 and Chapter 5.0, respectively). The purpose of this chapter is to discuss the ground water management strategies associated with the overall facility exclusive of the specific COA and landfill considerations. These include:

- perimeter buffer zone strategies,

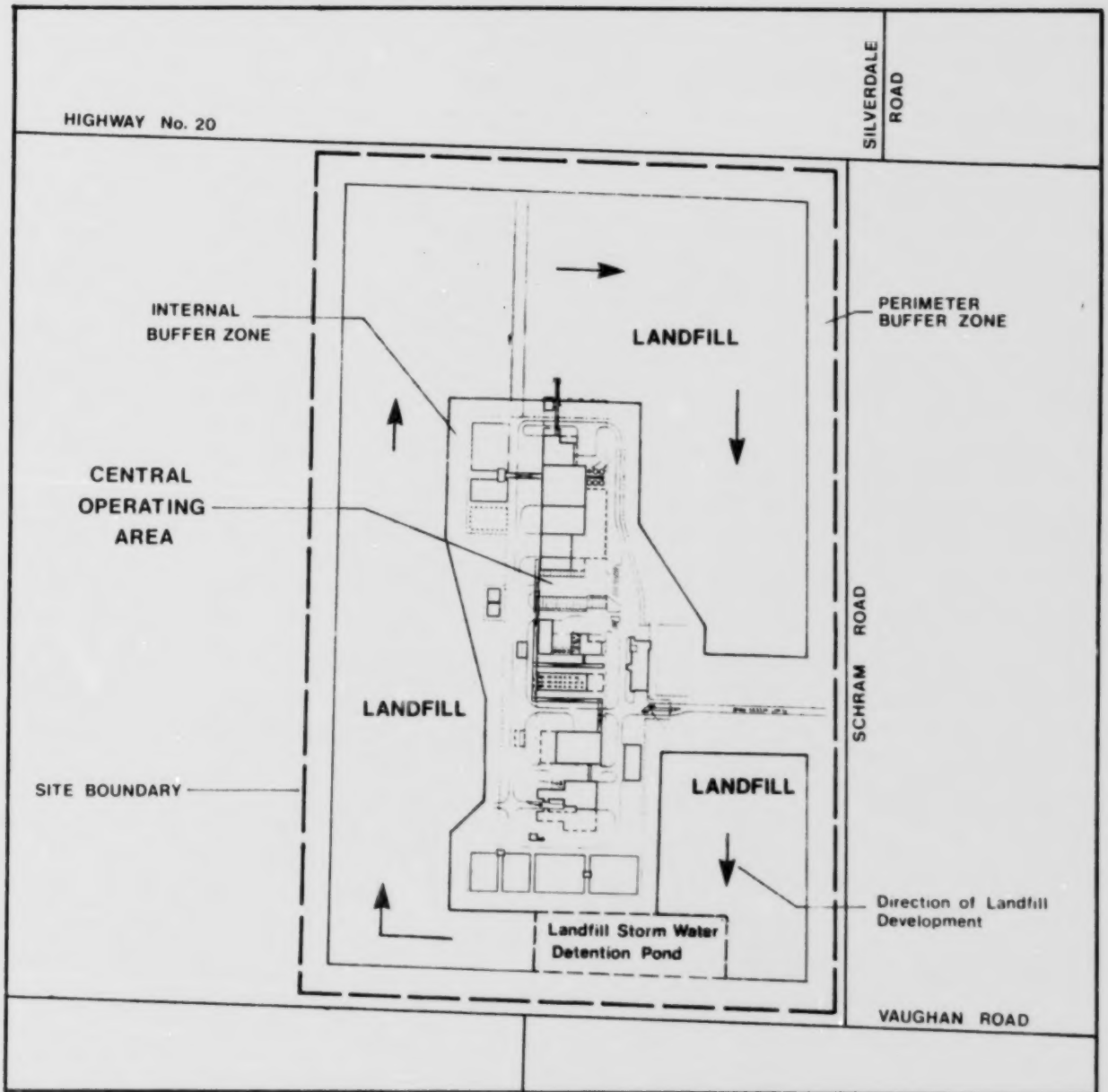


Figure 3·1
PLAN VIEW OF PROPOSED OWMC FACILITY

0 250 500
METRES

NOTE: (1) Details on the Central Operating Area are Provided in the Design and Operations report (Monenco, 1987).
(2) Landfill Storm Water Detention Pond Location Approximate Only.

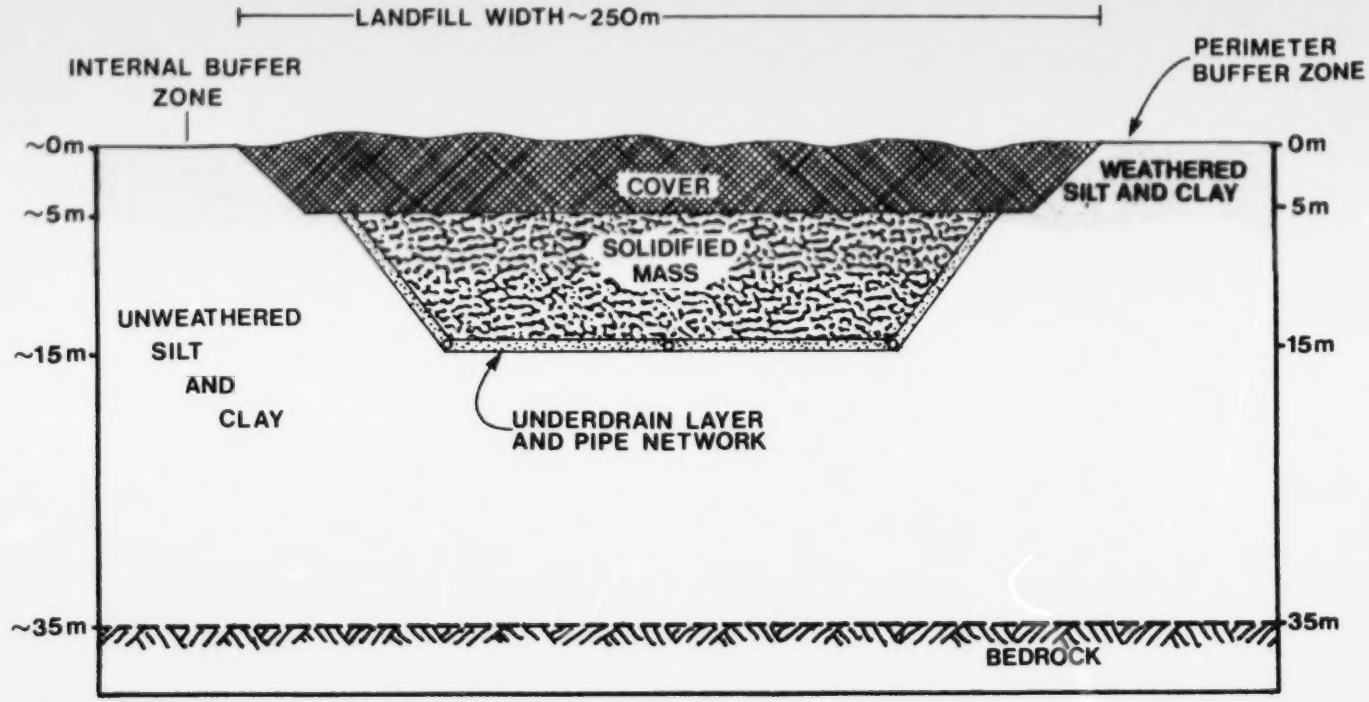


Figure 3-2
SCHEMATIC CROSS-SECTION THROUGH LANDFILL

NOTE : *NOT TO SCALE.*

Gartner Lee Limited

- general strategies common to all aspects of the facilities, and
- off-site strategies

In this chapter, ground water management strategies include the following:

- Sources: definition of the potential sources of contaminants (Section 3.2),

- Pathways: types of monitoring that are applicable to the various pathways by which contaminants might be expected to move off-site (Section 3.3), both from ground water flow and ground water quality perspectives,

- Receptors: types of monitoring that are applicable to the potential human receptors that the contaminants might reach (Section 3.4),

- Mitigation and Contingencies: identification of mitigation strategies by which predicted ground water impacts can be managed, and conceptual development of feasible contingency strategies which could be employed if unpredicted impacts were to occur (Section 3.5),

- Decommissioning: ground water management considerations related to the decommissioning of the facility (Section 3.6), and

- After Use: aspects related to end land use (Section 3.7).

3.2 POTENTIAL CONTAMINANT SOURCES

The principal sources of contaminants at the OWMC facility will be the landfill and the COA. Each of these possesses unique characteristics.

The landfill is a source of leachate (contaminants are introduced into the ground water in contact with the treated waste residues). The leachate will likely be produced slowly and over a very long time frame in keeping with the slow nature of ground water flow at the Preferred Site. The composition, rate of production, and rate and direction of movement of leachate has been predicted (GLL, 1987d). Monitoring will refine this

information throughout the operational life of the facility. Landfill leachate can be typified as a relatively uniform, slow-moving, predictable source.

Potential contaminant sources in the COA, on the other hand, can be typified as being highly variable. The COA facilities will be outfitted with multiple levels of engineering protection against contaminant releases. In addition, a comprehensive clean-up program will be in place and the site will be fully decommissioned after its assumed 50 year lifespan. Notwithstanding this, however, a "worst case" assumption has been made that any of several undetected, undecommissioned leaks or spill residuals of a variety of compositions could conceivably occur (GLL, 1987e). These leaks or spills have been classified in the following manner with respect to composition:

1) Miscible - contaminants which are dissolved in ground water, and

2) Immiscible - contaminants that are essentially insoluble and therefore remain as a separate phase. Immiscible phases can be further subdivided into:

   - Light Non-Aqueous Phase Liquids (LNAPL) - contaminants which are less dense than ground water ("floaters"), and

   - Dense Non-Aqueous Phase Liquids (DNAPL) - contaminants which are more dense than ground water ("sinkers").

Ground water management strategies that are specific to the potential contaminant sources at either the landfill or COA will be presented in detail in Chapter 4.0 and Chapter 5.0, respectively. They have been introduced in this chapter only to provide the basis for discussing overall (or common) ground water management strategies.

3.3 PATHWAY MONITORING

This section draws the link between predicted impacts, both on ground water flow and ground water quality, and the overall facility monitoring required to properly assess these impacts. Pathway monitoring for the overall facility is summarized for reference in Table 3-1 and discussed in the following sections.

TABLE 3-1: Overall Facilities Pathway Monitoring

LOCATION	OBJECTIVES	FREQUENCY	ANALYSES
PERIMETER BUFFER ZONE MONITORING: **********			
. Weathered silt and clay within perimeter buffer zone (existing and new monitors)	. To monitor for potential impacts on water table levels in the weathered silt and clay	. Quarterly (once per season)	. Measure water table elevations
	. To monitor for potential impacts on shallow ground water quality in the weathered silt and clay	. Quarterly (once per season)	. Comprehensive water chemistry (2) initially; scaled down to indicator parameters with time (1)
. Bedrock aquifer, upper 6m within perimeter buffer zone (existing and new monitors)	. To monitor for potential impacts on ground water availability in the bedrock aquifer	. Quarterly (once per season)	. Piezometric water level
	. To monitor for potential impacts on ground water quality in the bedrock aquifer	. Annually	. Comprehensive water chemistry (2); scaled down to indicator parameters with time (1)
. Bedrock aquifer zones of higher permeability below upper 6m of rock, within perimeter buffer zone (new monitors)	. To monitor for potential impacts on ground water flow in the deeper zones of lower permeability bedrock	. Quarterly (once per season)	. Piezometric water levels
	. To monitor for potential impacts on ground water quality in these lower permeability bedrock zones	. Annually	. Comprehensive water chemistry (2); scaled down to indicator parameters with time (1)

continues...

TABLE 3-1: Continued

LOCATION	OBJECTIVES	FREQUENCY	ANALYSES
OFF-SITE MONITORING:			
Weathered silt and clay, existing off-site locations	. To establish background trends in ground water flow and water table elevations in weathered silts and clays	. Quarterly (once per season) initially;	. Water table levels
	. To establish background trends in shallow ground water quality in the weathered silts and clays	. Quarterly (once per season) initially; program scaled down with time	. Comprehensive water chemistry (2); scaled down to indicator parameters with time (1)
. Bedrock aquifer, upper 6m, existing off-site locations	. To monitor for potential impacts in the bedrock aquifer downgradient of the facility	. Quarterly (once per season)	. Piezometric water levels
	. To monitor for potential impacts on ground water quality in the bedrock aquifer downgradient of the site	. Annually	. Comprehensive water chemistry (2); scaled down to indicator parameters with time (1)
	. To establish background trends in ground water flow and elevations in the bedrock aquifer upgradient of the site	. Quarterly (once per season)	. Piesometric water levels
	. To establish background trends in ground water quality in the bedrock aquifer upgradient of the site	. Annually	. Comprehensive water chemistry (2); scaled down to indicator parameters with time(1)

(1) Monitoring program to be scaled down in frequency and water chemistry analyses (indicator parameters only) as waste profile and leachate chemistry data will justify

(2) Comprehensive water chemistry analysis includes:
- . major ion chemistry,
- . other inorganic parameters identified in the Ontario Drinking Water Objectives,
- . qualitative scan to identify the presence of organic species, and
- . detailed testing should organic species be identified

3.3.1 Ground Water Flow

Ground water flow can be impacted only in-as-much as the availability of ground water for any uses is affected. In the vicinity of OWMC's Preferred Site, ground water wells occur in the upper portion of the bedrock aquifer, and in a few instances shallow wells also occur in the weathered silt and clay (Figure 1-4). No wells are known, nor expected in future to be developed, in the unweathered silt and clay (its low permeability makes it an extremely poor water producer). Therefore, overall facility monitoring to assess potential ground water flow impacts considers only the surficial weathered silt and clay and the underlying bedrock aquifer. Monitoring in the unweathered silts and clays is incorporated into landfill and COA specific monitoring (Chapters 4 and 5).

Previous OWMC related impact assessment studies indicated that neither the landfill nor the COA operations would have any measurable impact on off-site ground water availability in shallow weathered silt and clay wells (GLL 1987d; 1987e). This can be checked through monitoring of water table elevations in water table monitors (standpipes) in the perimeter buffer zone. In addition to existing standpipes, several new shallow ground water monitors should be installed in the perimeter buffer zone for this monitoring purpose. Construction and location of these monitors is discussed in Section 3.3.2. Quarterly (once per season) water table measurements should be taken in these shallow monitors.

Also, there already exists four off-site monitoring stations, each of which contains a standpipe monitor. These monitors are remote from the site and therefore quarterly water level measurements in these standpipes will provide background data regarding naturally occurring trends in water table depths and shallow ground water flow.

Immeasurable off-site impacts were also predicted for ground water flow and availability in the bedrock aquifer as a result of the OWMC facility. General predictive monitoring to check this assessment would involve a number of bedrock piezometers of varying depths located in the perimeter buffer zone. Details regarding these monitors are provided in Section 3.3.2. Water level measurements should be undertaken quarterly (once per season) in these monitors.

In addition, the four existing off-site monitoring locations each contain a bedrock piezometer. These should be included in the quarterly water level measurements to establish naturally occurring (background) trends in the bedrock upgradient of the site and as a further check on potential impacts downgradient.

3.3.2 Ground Water Quality

As with ground water flow impacts, consideration of impacts on ground water quality must also account for there being an ultimate use made of the ground water. As indicated in Section 3.3.1, the focus of the ground water pathway monitoring must be the surficial weathered silt and clay zone and the bedrock aquifer, since these are where ground water supplies and where linkage to surface water occur (weathered silts and clays only in the latter case).

Weathered Silt and Clay

Previous OWMC related studies reached the following conclusions regarding off-site ground water quality impacts in the weathered silt and clay zone (see also Figure 1-4):

- in a very conservative assessment, some contaminants in the landfill leachate might diffuse upward into the landfill cover, then potentially migrate off-site in the weathered silt and clay. Realistically, however, upward diffusion is unlikely to occur and it if did contaminant concentrations are generally expected to be reduced to acceptable levels by the processes of geochemical and biochemical attenuation and dilution in the shallow ground water and surface water in the swales on the site (GLL, 1987d), and

- ground water within the weathered silt and clay may become locally contaminated in the COA due to inaccessible spills and undetected leaks. Providing all granular-filled service trenches are properly sealed, however, it is predicted that this contamination will not migrate off-site in the weathered silt and clay since the COA is at a minimum about 175 metres from the nearest property boundary and in most cases in excess of 250 m (with landfill areas intervening). Continuous, extensive lateral ground water flow and migration of

non-aqueous phases in the weathered silt and clay is improbable across this distance without discharge to on-site swales or ditches (GLL, 1987e).

Shallow ground water quality monitoring will be undertaken in the perimeter buffer zone (Figure 3-3) to check these predictions, in addition to specific COA and landfill monitoring programs (Chapters 4.0 and 5.0). The exact number and location of shallow ground water monitors in the perimeter buffer zone cannot be determined at this time. It will be necessary to ensure that these monitors are in locations compatible with other structures (i.e., berms, ditches and roads) in the perimeter buffer zone. A monitor should be constructed in the perimeter buffer zone adjacent to each years landfilling activities. A reduction in the number of these monitors should be achievable in later years of operation dependent upon the results of performance monitoring in the shallow ground water of the landfill cover and COA operations.

Ground water quality monitoring in weathered (fractured) soils is a developing science. As such, there is no consensus among experts on the most effective type of monitor. Quite likely, several types will be employed in the perimeter buffer zone, examples of which are illustrated in Figure 3-4, until the most effective method can be established through discussions with MOE.

In addition to the shallow ground water monitors constructed in the perimeter buffer zone, the existing off-site standpipes at four locations should also be monitored for ground water quality (Figure 3-3). This will help establish naturally occurring (background) trends in shallow ground water quality.

The shallow ground water monitors described above should be sampled quarterly (once per season). Testing should include a comprehensive list of parameters, including, at a minimum, the following:

- major ion chemistry,
- parameters identified in the Ontario Drinking Water Objectives (M.O.E., 1983)

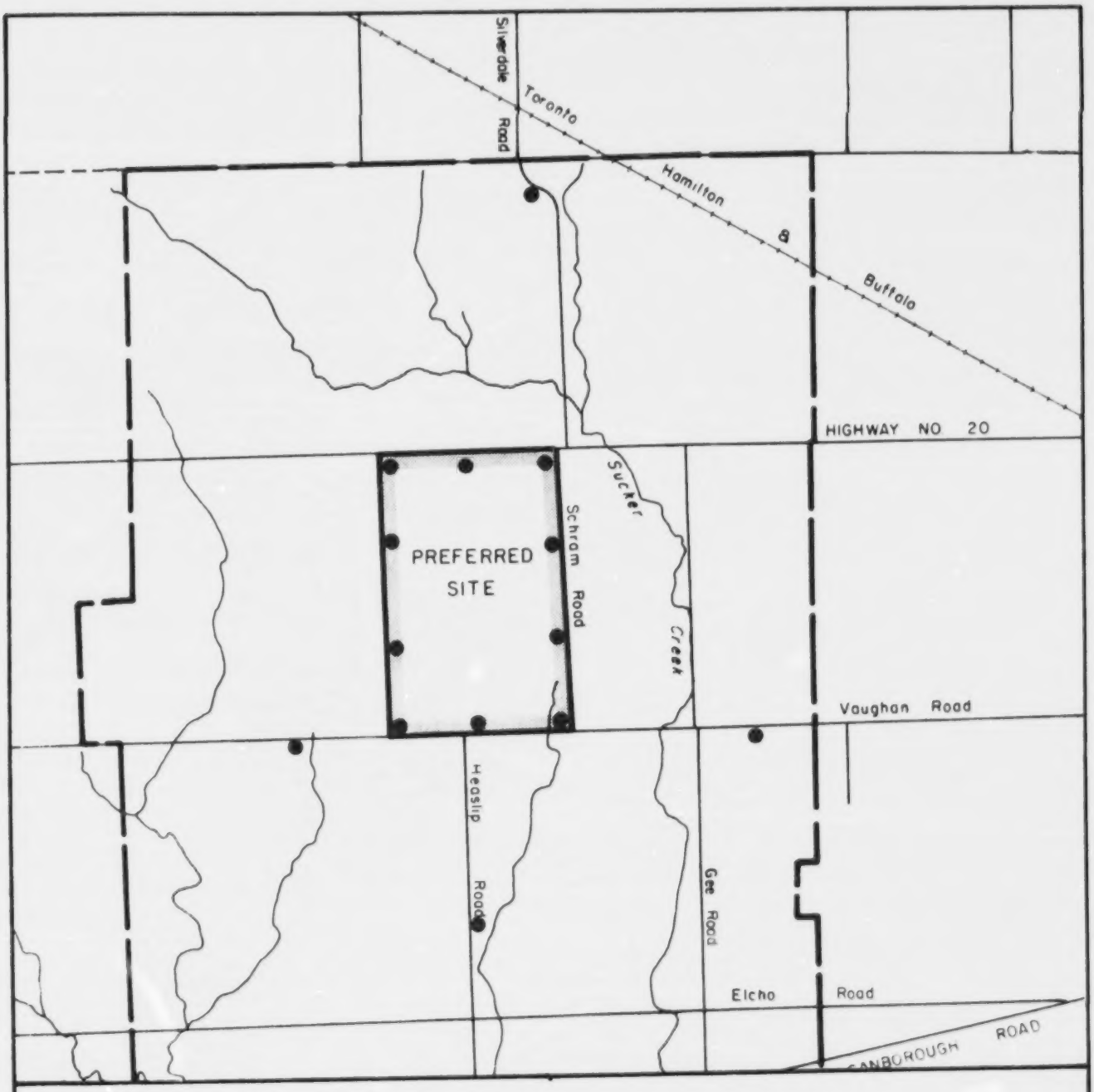


Figure 3-3
SHALLOW GROUND WATER MONITORING LOCATIONS - OVERALL FACILITY MONITORING

- ● Existing Shallow Ground Water Standpipe Monitor To Be Included In Program (where possible)

Perimeter Buffer Zone Areas - Other Shallow Ground Water Monitors To Be Constructed In This Area

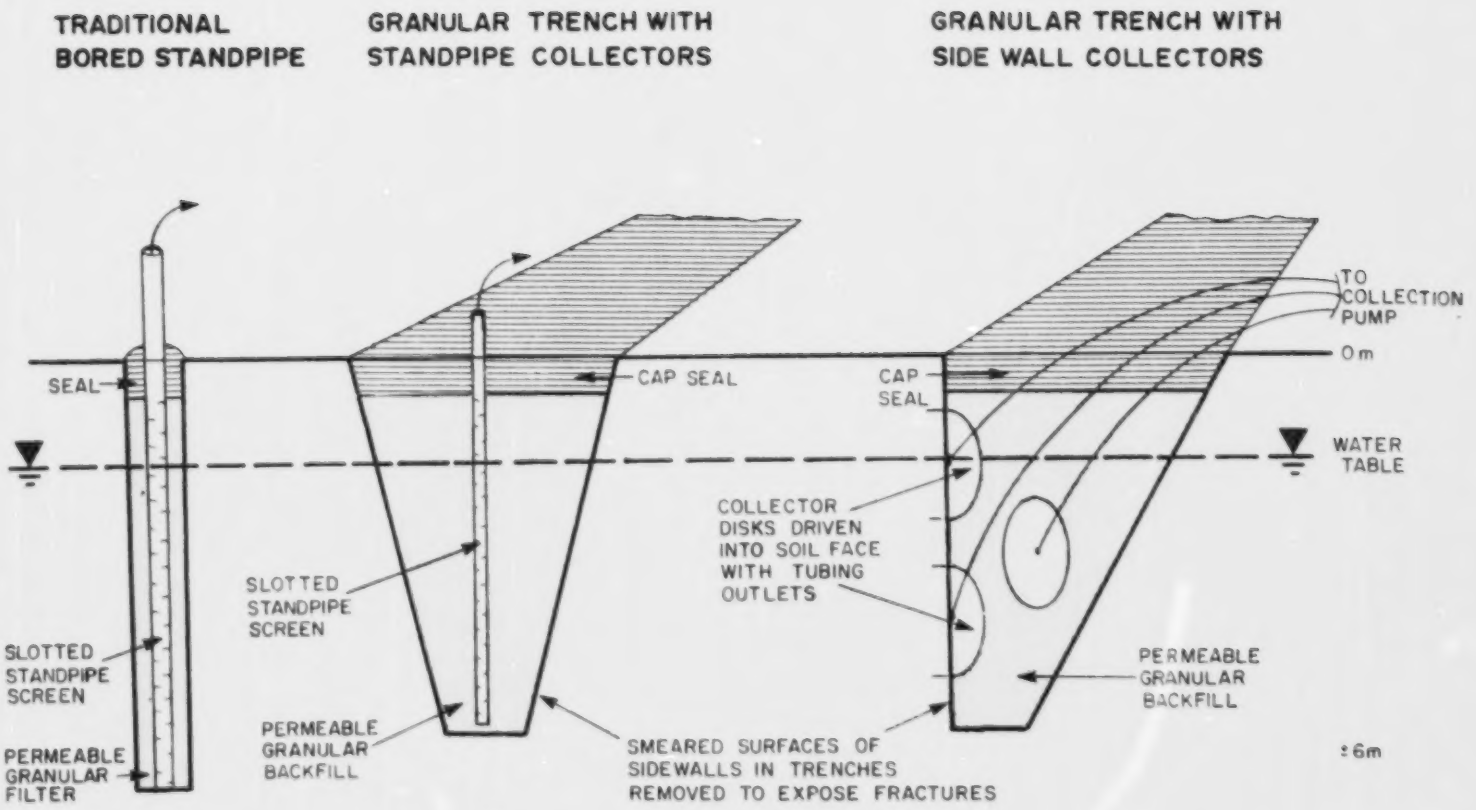


FIGURE 3-4: EXAMPLE CONSTRUCTION TECHNIQUES FOR SHALLOW GROUND WATER MONITORS IN WEATHERED OVERBURDEN SOILS

Gartner Lee Limited

- qualitative scan to identify the presence of organic species, and
- detailed, quantitative testing should organic species be identified.

The general approach will be to undertake more detailed testing in the early operational years, then scale the testing program down to indicator parameters only after the landfill leachate has been characterized and the wastes arriving at the COA profiled.

The scaling-down of the program and the selection of indicator parameters will be developed with time as operational and monitoring data is accumulated.

Bedrock Aquifer

The following predictions have been made regarding potential ground water quality impacts in the bedrock aquifer (see also Figure 1-4):

- undetected leaks and inaccessible spills in the COA should not impact ground water quality in the bedrock aquifer assuming there are no "short circuit" pathways (e.g., unsealed boreholes) through the unweathered silt and clay. However, due to the uncertainty about types of contaminants, depths of decommissioning and the concentrations that might remain in the ground, this should be assessed on a case by case basis at the time of decommissioning (GLL 1987d), and;

- Due to processes such as dilution, adsorption, solubility controls, and degradation, all of the constituents for which landfill leachate estimates are available, are not anticipated to impact the bedrock aquifer with the exception of chloride. Because of the very high concentrations predicted for the leachate and the non-reactive nature of chloride, there is a potential for the Reasonable Use Policy guildeline to be exceeded in the bedrock aquifer, although not for several hundred years (GLL 1987d).

Overall facility ground water quality monitoring can check these impact predictions. Ground water piezometer monitors have previously been installed in the upper bedrock

zone in ten locations in the perimeter buffer zone on-site, and at four off-site locations (Figure 3-5). These monitors should be retained if possible. Two additional piezometers are required directly downgradient (generally south) of the major landfill areas flanking the COA to the east and west (Figure 3-5).

All of the impacts and monitoring discussed previously have considered only the upper, permeable, portion of the bedrock (approximately 6 metres thickness). This is the zone where water wells in the site vicinity obtain their water. The baseline studies however, indicated that there were further permeable zones at depth in the bedrock interlayered with less permeable zones (GLL 1987a). It is not expected that any of these zones could be impacted by the OWMC facility because:

- the more permeable zones at depth are hydrogeologically separated by lower permeability zones, and
- vertical hydraulic gradients are very slight, and possibly upward which would limit downward contaminant migration deeper into the bedrock.

Furthermore, bedrock water wells in the site vicinity almost exclusively obtain water from the uppermost permeable zone; therefore, there is essentially no ground water use associated with deeper permeable zones.

Nonetheless, it is felt that some monitoring is warranted in the deeper permeable zones to check the prediction that deeper bedrock ground water will not be impacted. Pneumatic piezometers presently exist at depth at the monitoring locations in the northwest and southeast corners of the site. These should be monitored quarterly for water levels. However, additional piezometers (in each of the next two permeable zones beneath the upper bedrock aquifer) are proposed at two locations in the perimeter buffer zone, one directly upgradient and one directly downgradient of the facility (Figure 3-5). These should be measured for water levels quarterly and sampled for water quality as discussed below.

All bedrock piezometers in the perimeter buffer zone and off-site, with the exception of existing pneumatic piezometers, should be sampled and tested for water quality on an

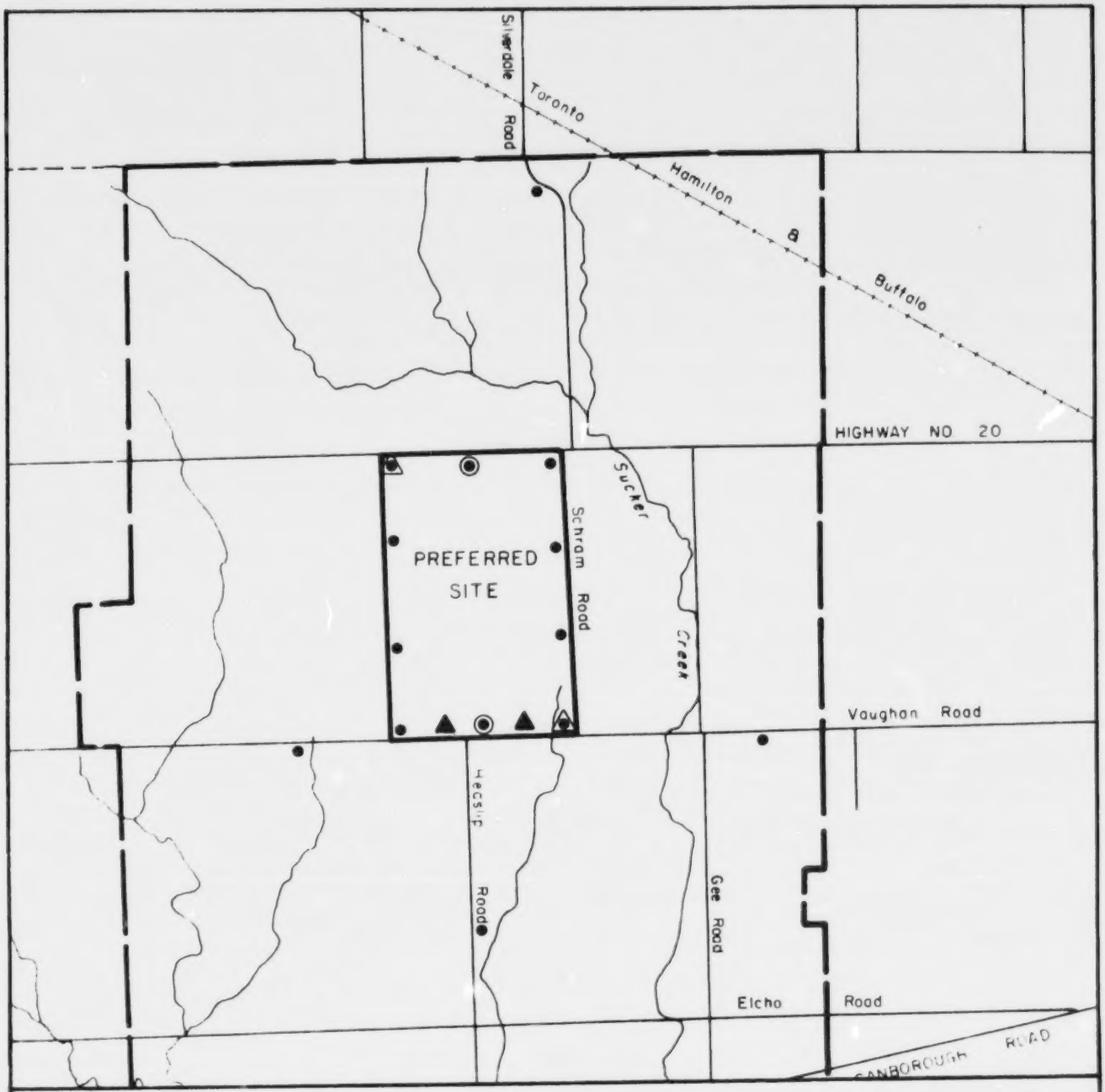


Figure 3·5
BEDROCK GROUND WATER MONITORING LOCATIONS - OVERALL FACILITY MONITORING

- • Existing Shallow Bedrock Piezometer To Be Included In Program (where possible)
- ▲ New Shallow Bedrock Piezometers To Be Installed
- ○ Locations Where Additional Bedrock Piezometers To Be Installed In Deeper Permeable Zone
- △ Locations Where Bedrock Pneumatic Piezometers Exist In Deeper Permeable Zones

annual basis. More frequent sampling is not considered warranted since contaminant movement through the overlying unweathered silt and clay is extremely slow and significant breakthrough is not expected for many hundreds to thousands of years. Testing should initially be comprehensive, including:

- major ion chemistry,
- parameters identified in the Ontario Drinking Water Objectives (M.O.E., 1983),
- qualitative scan to identify the presence of organic species, and
- detailed testing should organic species be identified.

The goal of the program should however be to scale back from detailed testing in the early operations years to selected indicator parameters, once the landfill leachate characteristics and waste profile at the COA are fully established.

3.4 RECEPTORS

The receptors are in this case humans or livestock who use the ground water that could be impacted by the OWMC facility. In Section 3.3 the two main ground water uses were identified as:

- water wells in the shallow weathered silt and clay, and
- water wells in the bedrock aquifer.

A water well monitoring program is necessary to confirm that receptors are not being impacted by the facility, beyond the assurances provided by the pathway monitoring (Section 3.3). Water well monitoring off-site is usually the mandate of the Ontario Ministry of the Environment. It should at a minimum include the following components:

- a complete inventory of existing water uses and water wells (much of this work has already been completed by OWMC; see GLL, 1987a),
- a process by which any proposed water well constructions in the vicinity extracting significant quantities of ground water are carefully regulated to ensure

compatibility with the OWMC facility (N.B. domestic wells likely do not fall into this category),

- a process by which new water well data is added to the inventory, and
- a process by which future proposed water uses other than wells (e.g., quarry dewatering) are regulated to ensure compatibility with existing and future water well uses and the OWMC facility, and
- a periodic sampling program to establish water quality in the site vicinity (both upgradient and downgradient).

3.5 MITIGATION AND CONTINGENCY STRATEGIES

3.5.1 Mitigation Strategies

Mitigation strategies specific to either the COA or landfill will be addressed in Chapters 4.0 and 5.0, respectively. The following are mitigation strategies which apply to the overall facility:

- All existing boreholes, monitors and water wells which are not required as part of the pathway monitoring program (Section 3.3, Chapters 4.0 and 5.0) must be properly sealed prior to site development to prevent these from becoming contaminant "short circuits". Appendix A of this report provides a detailed protocol for borehole, monitor and water well sealing at the OWMC site,

- All existing ground water monitors that will remain as part of the ongoing facility monitoring program should have their surface seals checked and replaced, if needed, to prevent surface contaminants from entering the boreholes. As well, these monitors should be provided with protection from facility construction and operations (e.g., fencing etc.), and

- existing service trenches and agricultural tile drains should be removed and/or properly sealed prior to site construction and operation to prevent enhanced contaminant movement along these artificial conduits.

3.5.2 Contingency Strategies

Contingency strategies are actions that could be employed should pathway or receptor monitoring indicate a catastrophic error in the ground water impact predictions. The contingency strategies presented here are conceptual, but feasible given today's technologies and the site setting.

Again, contingency strategies specific to the COA and landfill are developed in Chapters 4.0 and 5.0. The following presents conceptual contingency strategies relative to the overall facility (see also Figure 1-4).

Weathered Silt and Clay

The most applicable contingency for lateral contaminant migration in the weathered silt and clay is an interceptor trench fully across the path of an identified contaminant plume. The trench could be constructed just inside the property boundary to intercept contaminants before they migrate off-site. The construction and operation of an interceptor trench is schematically illustrated in Figure 3-6.

Other contingency methodologies will likely be developed as research into the hydrogeology of weathered overburden soils is undertaken. The results of this research should be periodically reviewed in order to assess its applicability to the OWMC site.

Bedrock Aquifer

The most appropriate contingency strategy for the bedrock aquifer given current technologies and the site setting is considered to be purge wells in the bedrock aquifer. Purge wells would likely consist of a single row or multiple rows of wells along the downgradient property boundary from which contaminated ground water is pumped. The wells would be designed such that their zones of ground water capture overlapped sufficiently to remove the bulk of the contamination (although 100% efficiency is generally not possible, sufficient capture may be achieved in order that off-site discharges meet regulatory requirements). Figure 3-7 schematically illustrates the construction and operation of purge wells.

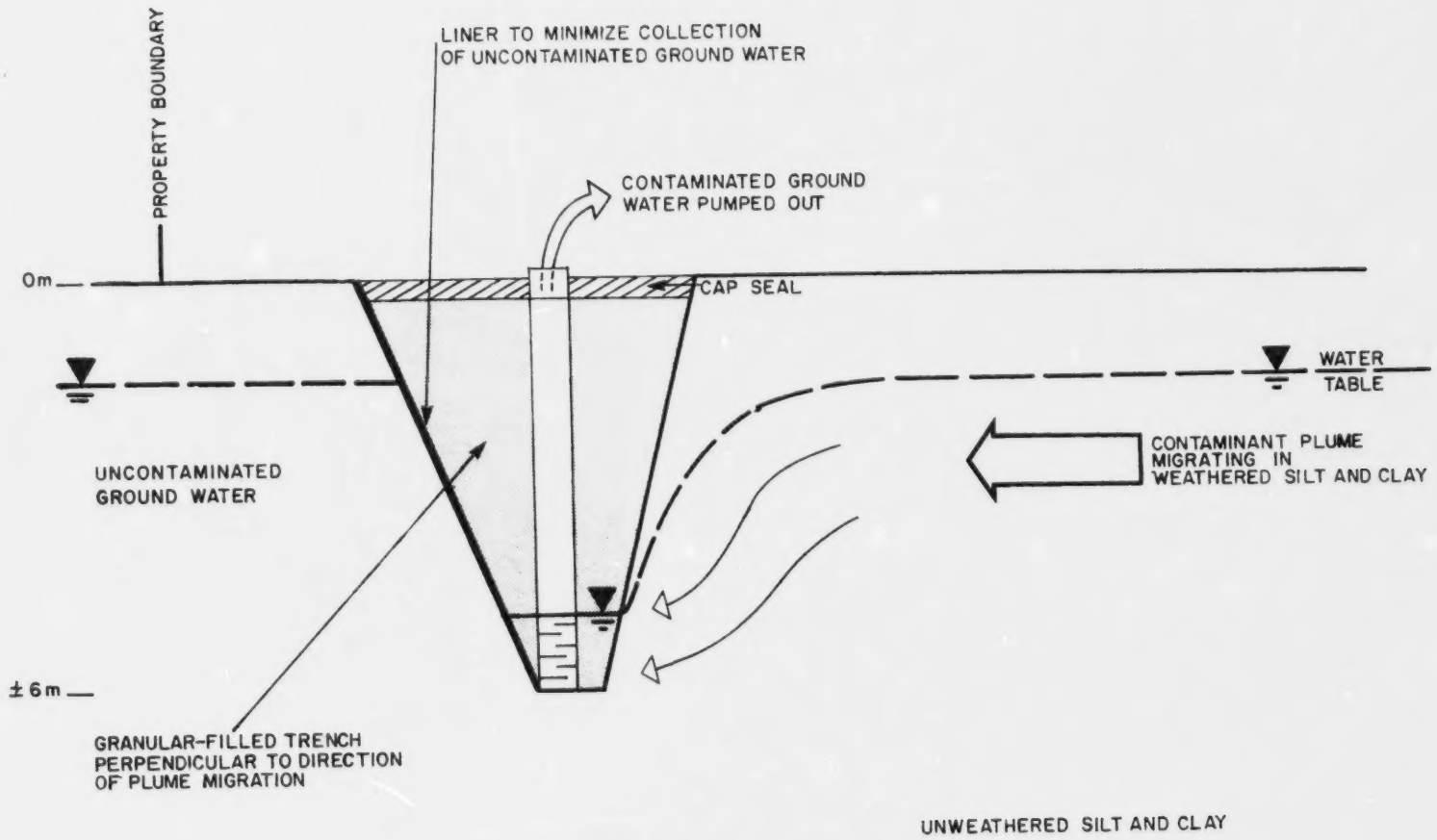
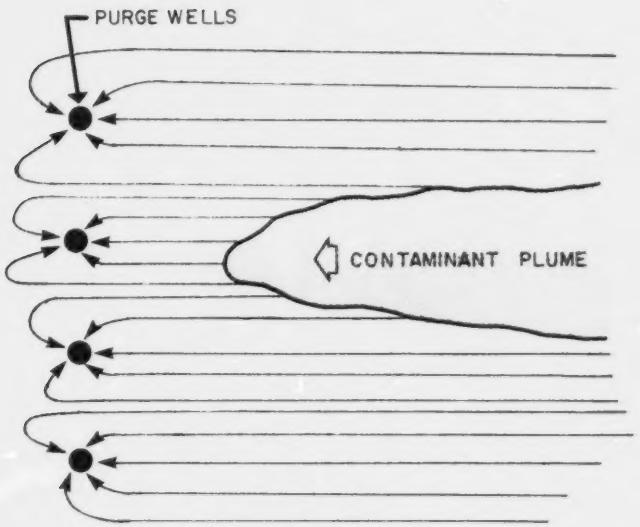


FIGURE 3-6: CONSTRUCTION AND OPERATION OF AN INTERCEPTOR TRENCH IN THE WEATHERED SILT AND CLAY

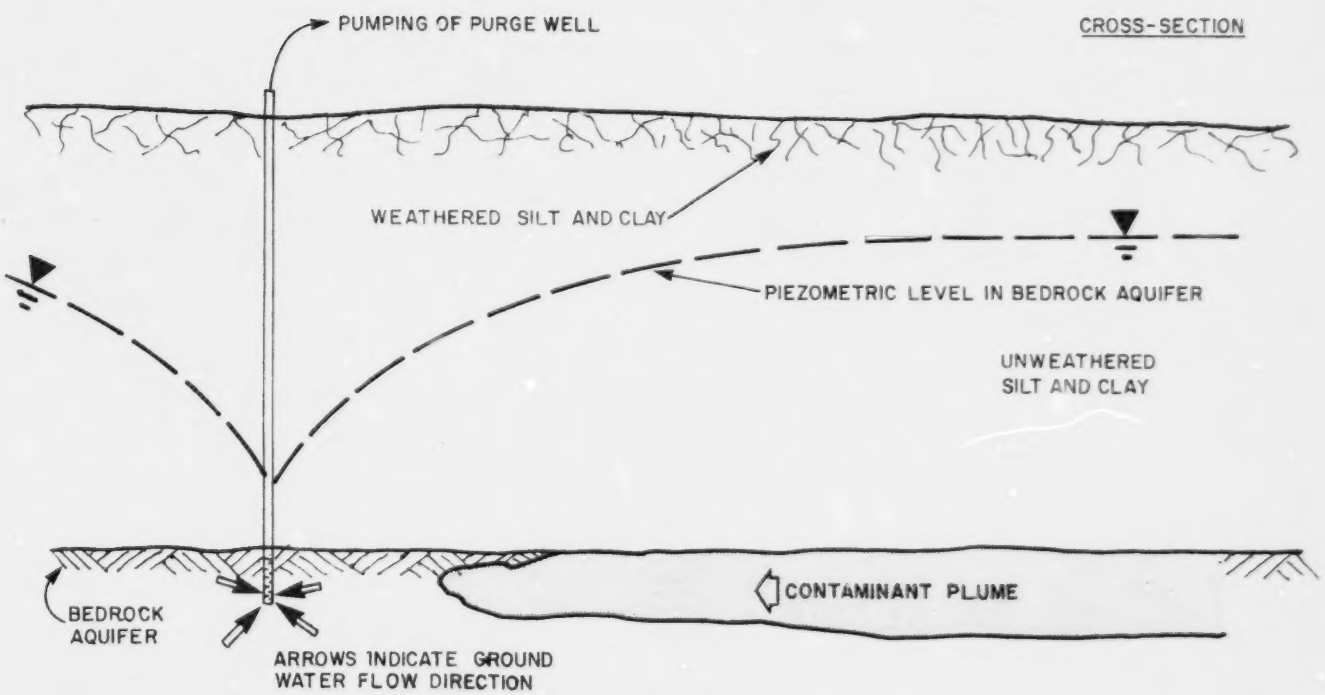
Gartner Lee Limited

FIGURE 3-7: CONSTRUCTION AND OPERATION OF PURGE WELLS IN THE BEDROCK AQUIFER



PLAN VIEW

NOT TO SCALE



CROSS-SECTION

The ultimate contingency strategy, should purge wells prove ineffective in containing contaminants on-site, is to provide an alternate source of water for affected users. The alternate source might include one or more of the following:

- drilled or bored wells in the weathered silt and clay zone,
- piped water, and
- trucked water.

Water treatment at individual wells might also merit some consideration.

3.6 DECOMMISSIONING STRATEGIES

Decommissioning strategies are for the most part specific to either the COA or the landfill and will be presented in Chapters 4.0 and 5.0, respectively. In terms of the overall facility, the only significance of decommissioning is that the monitoring programs will likely be scaled back at the time of decommissioning to the point where only overall facility monitoring for specific indicator parameters is required. This concept was discussed in Section 3.3.

3.7 END LAND USE

Certain considerations must be made respecting the eventual use of the OWMC facility after operations cease and the COA is decommissioned. It is almost certain that leachate will continue to be produced in the landfill for hundreds of years following facility closure. Current Ministry of the Environment policies and guidelines dictate that there be no construction on or within 30 metres distance of a closed landfill (Ministry of the Environment, 1986). While this would theoretically allow future development in the COA after decommissioning, it would seem prudent to prohibit such development given the proximity to the landfill.

In this spirit, OWMC has made a commitment to preserve their facility in government control of some form in perpetuity (Monenco, 1987).

4.0 CENTRAL OPERATING AREA

4.1 INTRODUCTION

The Central Operating Area (COA) consists of the following main components:

- an incineration plant to destroy organic wastes at high temperatures;
- a physical/chemical treatment plant to reduce or eliminate the hazardous components of inorganic wastes which are non-combustible;
- a solidification plant where treated residues from physical/chemical and incineration processes will be mixed with reagents such as cement to form a physically and chemically stable solid material suitable for disposal in the engineered landfill; and
- laboratory and administrative facilities;
- waste and reagent delivery and storage facilities.

The COA is located in the middle of the site and occupies approximately 19 ha of the 124 ha site. The COA is surrounded by the engineered landfill, which effectively provides approximately 175 to 400 m between the COA and the edge of the site.

The central operating area facilitates the receiving, unloading, separate storage and treatment of inorganic wastes and separate storage and treatment of organic wastes. The reader is referred to the "Design and Operations" report prepared by Monenco Limited (1987) for a more detailed discussion of the Central Operating Area design and operations.

This Chapter of the report describes:

- Sources: monitoring required at the source to characterize the contaminants and check the performance of the engineering containment systems (Section 4.2);

- Pathways: monitoring required along the ground water pathway to check facility impacts on the ground water flow system (ground water availability) and impacts on the quality of ground water along the hydrogeologic pathways from the facility (Section 4.3);

- Mitigation and Contingencies: mitigation and contingencies that may be triggered as a consequence of COA operations and monitoring (Section 4.4); and

- Decommissioning: COA decommissioning strategies.

Monitoring of potential COA impacts on ground water receptors is described in Section 3.0 of this report, the overall facility monitoring chapter.

4.2 SOURCE MONITORING

4.2.1 Contaminants Characteristics

A detailed tracking system will be in place during facility operations to record the composition, volume, location and movement of all wastes and reagents in the COA (Monenco, 1987). Therefore, should any subsurface contaminant occur it is assumed there will be sufficient information available about the character of the contaminant to allow an appropriate response to be immediately undertaken.

Further detailed monitoring of the character of potential contaminant sources at the COA during normal operations is impractical due to the wide variety of wastes/reagents that will be present at diverse locations throughout the facility. However, once a subsurface emission has been identified, one of the first steps in the remediation process should be to assess in detail the nature of the contaminant source as it exists in the ground water system. This is particularly important since:

- the operational tracking system for wastes and reagents may only provide general characterization of the emission, whereas minor or trace constituents in

the waste or reagents may be significant from a ground water impact standpoint (e.g., trace level toxic organic compounds),

- the operational tracking system may not provide certain hydrogeologic characteristics for the emission that will be important in assessing ground water impacts (e.g., solubility, density and viscosity relative to local ground water, etc.), and

- some emissions may be chemically transformed in the ground water system and will therefore have changing characteristics with time.

In summary, then, source monitoring with respect to emissions is only practical on a case-by-case response basis with the monitoring program tailored to the nature and location of the emission.

4.2.2 Performance Monitoring of Engineered Containment Devices

It is important to note that the probability of contaminant emissions to ground water is considered to be low as a result of the double levels of engineered containment that have been designed for the waste and reagent storage and transport systems (Monenco, 1987). An inspection program must be implemented as part of the facilities operations to ensure that the containment devices are functioning properly. This program will be planned during the detailed design phase specific to each containment system.

The performance monitoring program will include a variety of non-hydrogeologic inspections (for example, electrical/mechanical testing of pumps and level alarms, etc.). The majority of hydrogeologic performance monitoring should consist of visual inspection to ensure that leakage or spillage is not occurring and to check on the general integrity of containment devices (e.g., tanks, pipes, concrete-lined pits, dykes, etc.). One notable exception is the proposed liner system beneath potentially contaminated ponds. Ground water samples should be collected from below the liner using lysimeters and submitted for comprehensive ground water quality analyses to determine if any contaminants are leaking through the liner.

4.3 PATHWAY MONITORING

Pathway monitoring should be directed towards checking predicted impacts. The following sections review the COA impact predictions on ground water flow (availability) and ground water quality, respectively, and propose related monitoring techniques.

4.3.1 Ground Water Flow

The impact assessment studies for the COA reached the following major conclusion with respect to ground water flow (GLL, 1987e):

- the COA will not affect the availability of ground water in off-site wells.

The overall facility monitoring presented in Section 3.3 is designed to check this conclusion; further monitoring in the COA is not required in this regard.

Three ground water piezometers are recommended in the bedrock aquifer along the downgradient perimeter of the COA, primarily for water quality monitoring (see Section 4.3.2). Annual water level measurements in these monitors can be used to check the prediction that the COA will not affect ground water flow in the bedrock aquifer.

The impact assessment study also determined that shallow ground water flow in the weathered silt and clay may be locally changed from natural conditions due to the presence of COA facilities such as ditches, service trenches, tank pits, ponds, and building foundations. This will be reflected in local ground water table fluctuations. However, this is not considered to result in an impact since off-site ground water availability will not be affected. Therefore, routine monitoring of shallow ground water flow in the COA is not warranted.

Specific monitoring of shallow ground water flow may be required, though, as part of a spill or leak response to determine local contaminant migration pathways. This monitoring should be designed on a case-by-case basis.

4.3.2 Ground Water Quality

The following major conclusions were reached regarding potential ground water quality impacts resulting from the COA (GLL, 1987e):

- shallow ground water in the weathered silt and clay may become locally contaminated in the COA due to inaccessible spills or undetected leaks; the only means by which these contaminants could move off-site in shallow ground water is through granular-filled service trenches, and

- ground water quality in the bedrock aquifer will not be impacted, except if contaminants migrate through "short circuits" in the unweathered silt and clay such as unsealed boreholes or wells.

Shallow Ground Water Monitoring

The contamination that may occur in the weathered silt and clay in the COA may migrate in any number of directions due to the localized influences of ditches, service trenches, tank pits, ponds, and building foundations on shallow ground water flow. Therefore, general monitoring of shallow ground water quality within or around the perimeter of the COA is impractical, except for visual inspection of ditches and review of surface water testing results to identify any discharges of contaminated shallow ground water. The overall facility monitoring described in Section 3.3 will check that off-site impacts are not occurring in shallow ground water.

Specific shallow ground water quality monitoring is recommended on a case-by-case basis in response to contaminant spills or leaks in the COA. The development of these specific monitoring programs must consider the characteristics of the emission in establishing the testing requirements, as well as the rate and direction of localized contaminant movement in assessing monitoring frequency and locations. Long-term monitoring should be developed to evaluate any residuals that will remain after clean-up activities.

Sealing of service trenches was recommended to mitigate the potential for off-site contaminant migration in shallow ground water (GLL, 1987e). The installation of

standpipe monitors in any granular-filled service trenches that lead away from the COA is also recommended in order to check on the effectiveness of the trench seals. These monitors should be checked for the presence and identification of non-aqueous phase products. As well, ground water samples should be collected from these standpipes (located at the perimeter of the COA) on an annual basis and subjected to a comprehensive water chemistry analysis which includes:

- major ion chemistry,
- parameters identified in the Ontario Drinking Water Objectives (MOE, 1983),
- qualitative scan to identify the presence of organic species, and
- detailed testing should organic species be identified.

Additional parameters could be added to this list in response to a spill or leak of specific characteristics.

This monitoring should continue until the plant facilities are fully decommissioned.

Bedrock Aquifer Monitoring

Three bedrock piezometers are recommended in the upper permeable zone of the bedrock immediately downgradient of the COA. These locations should be within the buffer zone surrounding the COA. Monitors to bedrock within the COA are not recommended since these could be potential "short circuits" to the aquifer. These monitors should be sampled annually and tested for the comprehensive list of water chemistry parameters outlined previously.

Although impacts are not predicted on ground water quality in the bedrock aquifer from the COA, these monitors would provide an "early warning" of potential off-site contamination should this prediction prove inaccurate or if "short circuit" pathways exist. That is to say, identification of contaminants in these COA bedrock monitors would provide lead-time to implement contingency strategies prior to the contaminants reaching the overall facilities bedrock monitors in the perimeter buffer zone (see Section 3.3).

4.4 MITIGATION AND CONTINGENCY STRATEGIES

4.4.1 Mitigation Strategies

The primary mitigation strategies for the COA, beyond the existing containment features designed for the facility, include:

- immediate response (clean-up) of any spills or leaks which occur,
- maintenance or modification of engineered containment systems as required,
- sealing of service trenches to prevent off-site contaminant migration in shallow ground water (GLL, 1987e), and
- proper sealing of unused boreholes, ground water monitors, and wells to prevent "short circuit" migration of contaminants to depth (see Appendix A).

4.4.2 Contingency Strategies

Aside from plant decommissioning (which is discussed in Section 4.5) the contingency strategies for the COA are embodied in the overall facility decommissioning strategies presented previously in Section 3.4.2.

4.5 DECOMMISSIONING STRATEGIES

OWMC has made a commitment to decommission the facilities contained within the COA after their closure. Details regarding decommissioning are contained in the "Design and Operations" report (Monenco, 1987). This section is not intended to provide a detailed discussion of decommissioning, as large volumes of literature already exist with regard to decommissioning of industrial sites.

From a hydrogeologic perspective, the decommissioning process will need to comply with existing (and future) regulations and guidelines. One such important document is "Guidelines for the Decommissioning of Sites in Ontario" (M.O.E., 1987). Reference can be made to this document for a detailed discussion of decommissioning practices. In general, however, Figure 4-1 presents the basic approach to decommissioning with respect to geology/hydrogeology.

FIGURE 4-1: GENERAL APPROACH TO DECOMMISSIONING

STEP 1: Investigate the site:

(a) review existing data base accumulated during operations to identify possible contamination events and their present condition, and

(b) undertake further geologic/hydrogeologic investigations (i.e., drilling, soil and water quality monitoring, etc.),

STEP 2: Assemble all available data to fully characterize the existing subsurface conditions at the site,

STEP 3: Develop a decommissioning plan that considers:

(a) potential future impacts,
(b) existing regulations and guidelines,
(c) resulting clean-up criteria for soils and ground water, and
(d) disposal options for excavated soil and extracted ground water.

STEP 4: Gain approval for the decommissioning plan, and

STEP 5: Implement the decommissioning plan, and

STEP 6: Monitor the effectiveness of the decommissioning in the post-closure period.

5.0 LANDFILL

5.1 INTRODUCTION

In addition to general facility monitoring (Chapter 3), monitoring specific to the landfill should be undertaken to assess landfill performance. As well, there are contingency actions and aspects of decommissioning that can be considered specific to the landfill. This Chapter describes:

- Containment: briefly reviews the landfill design and operation (Section 5.2),
- Source: describes monitoring within the solidified material (the source) to refine leachate quality and assess hydraulic performance of the landfill (Section 5.2),
- Pathways: describes monitoring of ground water flow and ground water quality in the cover and native soils immediately adjacent to the solidified material (the pathways) Section 5.4),
- Mitigation and Contingencies: discusses mitigation and contingency strategies specific to the landfill (Section 5.5), and
- Decommissioning: discusses decommissioning strategies and end land use specific to the landfill (Section 5.6).

5.2 OVERVIEW OF THE LANDFILL DESIGN AND OPERATIONS

The proposed design and operation of the landfill is described in detail in the "Design and Operations" report (Monenco, 1987). Only a brief overview is presented here.

The landfill will surround the Central Operating Area as shown in Figure 3-1 (Chapter 3). A schematic cross section through the landfill is shown in Figure 3-2 (Chapter 3). This type of design is referred to as the shallow entombed landfill. The landfill excavation will extend approximately 15 m below ground. The solidified residues of waste treatment will be placed at a depth of 5 to 15 m. The upper 5 m will be a cover of

recompacted clay derived from the landfill excavation. The surface topography will be graded to simulate the existing ridge and swale network.

Landfill excavation will proceed as shown in Figure 3-1. Only an excavation sufficient to service 1 or 2 years of solidified material will be open at any one time. Final cover, grading and vegetation will proceed immediately upon completion of any portion of the landfill.

OWMC proposes to operate the landfill leachate collection system in passive mode. This means that leachate will not be collected. However, since access to the base of the landfill will be impractical after emplacement of the solidified material, an underdrain layer and pipe network is being installed as the landfill is constructed. The landfill underdrain would only be used (i.e., active operation) as a contingency if future environmental monitoring identifies a need.

5.3 SOURCE MONITORING

5.3.1 Leachate Quality

OWMC has made estimates of leachate quality based on published data and laboratory studies that include bench scale treatment of actual special wastes and one simulated waste followed by solidification of the residues and leaching of the solidified material. Due to the paucity of supporting leachate data from operating landfills in which only the solidified residues of waste treatment are disposed, there are inherent uncertainties in the estimated leachate quality. Therefore monitoring of the landfill leachate quality should be undertaken to confirm its characteristics.

Leachate quality monitoring should consist of;

(1) laboratory leaching tests, and

(2) sampling of leachate within the landfill.

These programs are summarized in Tables 5-1 and 5-2 and discussed in more detail in the following sections.

TABLE 5-1: Leachate Quality Monitoring - Laboratory Leaching Tests

LOCATION	OBJECTIVES	FREQUENCY	ANALYSES
. Collect samples from selected batches of solidified material	. For laboratory leaching tests . To identify potentially leachable constituents associated with waste and residue types, treatment processes and solidifications for (1) correlation with actual leachate data, (2) assessing new wastes and changes in treatment and solidification processes, (3) assessing the effectiveness of various mitigative efforts in improving leachate quality	. Sample most batches until data are considered representative of the majority of wastes, residues, processes and solidification formulations	. Leaching tests on cured samples of the solidified material using a solution similar to shallow ground water . Analyze for constituents known to be in waste or residue plus general chemistry, major ions, constituents in Ontario Drinking Water Objectives and scans for identification and quantification of organics

TABLE 5-2: Leachate Quality Monitoring - Leachate Sampling within the Landfill

LOCATION	OBJECTIVES	FREQUENCY	ANALYSES
. Within solidified material, near its contact with the cover (one monitor in the portion of the landfill completed each year)	. To characterize leachate that could potentially diffuse up into cover and shallow ground water	. Monthly, to establish data base and determine temporal variability; scale down to less frequent with time	. As wide a range of contaminants as possible including: general chemistry; major ions; all constituents listed in the Ontario Drinking Water Objectives; metals scans; scans for identification and quantification of organices
. Within the underdrain layer (same locations as above)	. To characterize leachate that could potentially migrate downwards into the unweathered silt and clay, towards the aquifer	. As above	. As above

Laboratory Leaching Tests

Samples from selected batches of solidified material (after curing) should be leached in the laboratory with aqueous solution to assess the potential leachability of various contaminants. Since the OWMC facility will treat and solidify on a batch basis (Monenco 1987), the leaching results can be correlated to the type(s) of waste, treatment and solidification.

Guidance on leaching test procedures should be obtained from OWMC's leachate quality consultants. The aqueous solution used should simulate the composition and conditions of on-site shallow ground water. Water infiltrating through the 5 m cover will most likely generate the majority of leachate.

Initially, testing of almost all batches should be completed until a data set is obtained that is representative of the typical waste profile, treatment residues and solidification mixtures at the facility. The chemical parameters analyzed in each leach test should be based upon the composition of the waste or residue from which the batch of solidified material originated. All analyses should also include general chemical indicators such as pH, conductivity and dissolved organic carbon; major ion chemistry; metal scans; and a scan for identification and quantification of organic contaminants.

Leachate Sampling Within the Landfill

Sampling to characterize leachate quality within the landfill should be collected from ground water monitors located:

(1) within the solidified material near its contact with the cover, and

(2) within the underdrain layer.

These locations are illustrated in Figure 1-4 (back pocket).

Leachate within the solidified material, near its contact with the cover, is representative of leachate which could potentially migrate upwards by diffusion into the cover. Leachate within the underdrain is representative of that which could potentially migrate

downward by diffusion and very slow ground water flow, into the unweathered silt and clay.

To assess spatial variability, a set of these monitors should be installed in the landfill portions completed each year. As well, the monitors within the underdrain should be sampled to collect both a point sample and pumped to collect an integrated sample representative of average leachate quality over a wide area.

Sampling frequency should begin at once per month to establish a data base and determine temporal variability. Subsequent monitoring should be at a reduced frequency given the anticipated very slow leachate migration rates (GLL 1987d). The reduced frequency rate and the time at which this is initiated will depend upon the results of the initial, more frequent sampling and on regulatory requirements.

For complete characterization, leachate samples should be analyzed for as wide a variety of contaminants as possible, including: indicators of general composition (pH, conductivity, dissolved organic etc.); major ion chemistry; metals scans; all constituents listed in the Ontario Drinking Water Objectives; and scans for identification and quantification of all organic constituents.

Initiation of sampling will be dependent upon the time required to saturate the solidified material (i.e., for leachate to develop that is collectible in ground water monitors). This time period is presently unknown, but is likely in the order of years. In the event that saturation is not achieved within a few years of solidified material emplacement, unsaturated monitoring techniques should be considered to collect preliminary data at an early stage of operation.

In the event that the leachate collection system is activated, samples of leachate should also be collected from the outlet of the underdrain pipes, to characterize the quality of leachate for treatment related considerations.

5.3.2 Ground Water Flow

To check that the landfill is performing as expected with respect to ground water flow, requires an integration of source specific monitoring within the solidified material and pathway monitoring within the cover and adjacent native soils. For this reason all of the landfill specific monitoring of ground water flow is described in the following Section.

Potential effects of the landfill on ground water flow have been assessed and reported in GLL (1987d). The performance related conclusions of this report are summarized below. Also described is the monitoring that should be conducted to check these conclusions. This monitoring is also summarized in Table 5-3 and illustrated in Figure 1-4.

During Construction

The effects of landfill construction (i.e., excavation) on the water table in the surrounding native soils are predicted to be minor and are not expected to extend more than several metres to a few tens of metres from the excavation.

The water table monitors installed in the weathered silts and clays within the 50 m wide perimeter buffer zone as part of the overall facility monitoring program (Chapter 3) can be used to check this conclusion, provided they are installed adjacent to landfill areas prior to their excavation.

Completed Landfill - Passive Mode

(1) After cover emplacement, the water table is predicted to equilibrate in the cover at a depth similar to the water table in the surrounding soils.

Water table monitors can be installed in the cover to check this conclusion.

(2) Ground water flow through the solidified material is predicted to be downward.

This can be assessed based on water level measurements in the leachate quality monitors (Section 5.3.1) which are installed in the solidified material near the

TABLE 5-3: Performance Monitoring of Landfill - Ground Water Flow

LOCATION	OBJECTIVES	FREQUENCY	ANALYSES
. Water table monitors in weathered silt and clay of perimeter buffer zone adjacent to open landfill excavations	. To monitor effect of the landfill on the water table during excavation and emplacement of the solidified material and cover	. Monthly, starting 6 months prior to excavation, during excavation and emplacement of solidified material and cover, and 6 months after completion	. Measure water table levels
. Water table monitors in the cover (at the same locations as the leachate quality monitors (Table 5.2))	. To monitor the rate of saturation of the cover plus water table condition in the cover . To monitor hydraulic conductivity of cover and its changes with time	. Monthly, until equilibrium water levels achieved, then 4 times per year (i.e. once per season) . Hydraulic conductivity testing once per year	. Measure water levels . Hydraulic conductivity testing
. Leachate quality monitors in solidified mass and underdrain (see Table 5-2)	. To monitor rate of saturation of the solidified material plus ground water flow directions and hydraulic gradients within the solidified material and underdrain . To monitor hydraulic conductivity of solidified material and its changes with time	. As above	. Measure water levels . Hydraulic conductivity testing
. Piezometer monitors in the unweathered silts and clays below the landfill (at same locations as above)	. To monitor ground water flow direction and hydraulic gradients in the unweathered silt and clay below the landfill	. As above	. Measure water levels

cover and at the base of the solidified material in the underdrain layer. These monitors can also be used to monitor the rate of saturation of the solidified material.

(3) Ground water flow is predicted to be downward from the sides and bottom of the landfill with the majority of the hydraulic head loss occurring in the unweathered silts and clays below the landfill rather than in the solidified material.

To check this conclusion, ground water monitors should be installed in the unweathered silts and clays below the landfill and interpreted in conjunction with the water table monitors in the cover and the leachate quality monitors in the solidified material. The monitors below the landfill must not penetrate into the lower till or bedrock to prevent them from becoming "short-circuits" for contaminant movement to the aquifer.

The monitors in the cover and below the landfill should be installed in the same location as the leachate quality monitors (i.e., initially, one location per landfill portion completed each year).

As part of the ground water flow monitoring, hydraulic conductivities of the cover, solidified mass and underdrain layer should also be determined for in-situ conditions. This can be completed through in-situ hydraulic conductivity testing of the monitors in these units. This data should be supplemented with porosity determinations and visual inspection of the structure of these units.

Completed Landfill - Active Operation

Test pumping of the underdrain should be conducted as sections are completed to check that the design will perform as expected, should the underdrain ever be required.

In the event that the underdrain is activated the previously described ground water flow monitoring program can be used to assess underdrain performance provided that the

monitors are installed at the midpoint between drain pipes. This will be the point of maximum hydraulic head in the drain layer and water table within the landfill.

Lysimeters should also be installed in the cover to measure the amount of infiltration during active operation. The amount of infiltration during active operation is directly proportional to the amount of leachate produced.

5.4 PATHWAY MONITORING

5.4.1 Ground Water Flow

Ground water flow monitoring within and immediately around the landfill is described in Section 5.3.2. The assessment of potential impacts of the landfill on ground water flow (GLL 1987d) concluded that the landfill should have no significant off-site effects on the water table and on ground water flow in the bedrock. These effects can be monitored as part of the overall facility monitoring in the perimeter buffer zone as described in Chapter 3.

5.4.2 Ground Water Quality

Potential impacts of the landfill on ground water quality have been assessed and are reported in GLL (1987d). The conclusions of this report are summarized below. Also described is the monitoring that should be conducted to check these conclusions. This monitoring is also summarized in Table 5-4 and illustrated in Figure 1-4.

(1) In a very conservative assessment, chloride in the landfill leachate might diffuse upward into the shallow ground water of the landfill cover and discharge to surface waters in the swales.

However, upward diffusion of chloride may not even occur. For other contaminants, concentrations are expected to be reduced to acceptable levels by the processes of geochemical and biochemical attenuation and dilution in the shallow ground water and surface water in the swales on the site (GLL, 1987d).

The monitors installed to assess water table conditions within the cover (Section 5.3.2) can also be sampled to assess shallow ground water quality. Monitoring of

TABLE 5-4: Performance Monitoring of Landfill - Ground Water Quality

LOCATION	OBJECTIVE(S)	FREQUENCY	ANALYSES
. Water table monitors in the cover (some monitors as for ground water flow monitoring (Table 5-3))	. To monitor if leachate is diffusing upward into shallow ground water of cover	. Quarterly (once per season)	. Same constituents as leachate quality monitoring (Table 5-2) until indicator parameters can be selected. Future monitoring to focus on indicator parameters except for one full chemical scan each year
. Piezometer monitors in the unweathered silts and clays below the landfill (same monitors as for ground water flow monitoring (Table 5-3))	. To provide early warning of contaminant migration below landfill	. Quarterly to begin; reducing to once per year if contaminant movement is confirmed to be slow	. Same as above
. Soil cores, one two metres into unweathered silts and clays below landfill (at locations near the ground water quality monitor)	. To establish contaminant concentration profiles in the soil and pore waters for comparison to predicted migration rates and patterns	. Once every five years starting five years after emplacement of solidified material	. Leachate indicator parameters. Additional analysis will depend upon leachate quality, pore water extraction techniques, soil analysis techniques, amount of soil available etc.

shallow ground water quality in the adjacent native soils is included as part of the overall facility monitoring in the buffer zone as described in Chapter 3.

Monitoring of surface water quality draining from the swales on the surface of the landfill should also be undertaken, since shallow ground water discharges to these swales. This will be achieved by collecting and testing water samples from the Landfill Storm Water Detention Pond (Monenco 1987). This pond receives all run-off from the surface of the landfill.

(2) Contaminant migration below the landfill into the unweathered silts and clays will be very slow. Conservative (non-attenuated) constituents such as chloride will only penetrate on the order of metres during facility life. However, ground water quality in the bedrock aquifer may potentially exceed the Reasonable Use Policy guideline for chloride in several hundred years. Attenuated constituents will only penetrate on the order of centimetres during facility life and are not anticipated to impact the aquifer (GLL, 1987d).

The monitors installed in the unweathered silts and clays below the landfill to assess ground water flow can also be sampled to monitor contaminant migration below the landfill. However, it is most important that these monitors are sealed properly to prevent leachate leakage down the borehole annulus.

In addition, undisturbed soil cores should be collected one to two metres into the soils directly underlying the landfill. Some of these cores should be sectioned into thin slices and each slice chemically analyzed. Other cores should be used for pore water squeezing, with chemical analysis of the extracted pore water. These techniques are required in addition to the ground water monitors to to establish concentration profiles over the very short distances contaminants are anticipated to be present. Establishing concentration profiles over small distances of metres to centimetres is not practical with traditional ground water monitors. The concentration profiles can be compared to predictions of migration rates and processes (i.e., diffusion dominated migration, adsorption, etc.).

Monitoring of water quality in the bedrock aquifer directly below the landfill is not recommended. Installation of such monitors could potentially result in "short-circuits" for leachate to reach the aquifer. The above noted monitoring program in the unweathered silts and clays will provide ample early warning of contaminants potentially migrating towards the aquifer. Water quality monitoring in the aquifer is covered as part of the overall facility monitoring program (Chapter 3).

A sampling frequency of four times per year is recommended for monitors in the cover to assess seasonal variations. Monitors below the landfill need only be sampled once per year because of the predicted very slow contaminant migration rates. However, in the initial years of operation more frequent sampling (4 times/year) of these monitors should be undertaken to confirm that migration is slow.

Ground water samples should be analyzed, at least initially, for the same wide range of parameters as for leachate characterization (Section 5.3.1). This should continue until sufficient data is available on leachate quality that leachate indicator parameters can be selected. Future monitoring can then focus on the indicator parameters, although a full suite of chemical analyses should continue to be done once per year at each monitor.

The locations for soil core sampling should be near the ground water monitors so results can be correlated. The first soil cores should not be collected until about five years after waste emplacement. (Note that if contaminants were migrating at significant rates in the soil they would be detected in the ground water monitors below the landfill). The time lag is recommended to allow sufficient time for a measurable concentration profile to develop. Since contaminant migration rates are concentration dependent in a diffusion dominated environment such as exists below the landfill, the length of time until the first soil cores are collected should be reviewed as more information becomes available on leachate concentrations. Subsequent sampling should continue at five year intervals (subject to review). The infrequent soil core sampling is recommended because of the anticipated very slow migration rates and to

minimize the number of holes drilled into the aquitard which separates the landfill and the bedrock aquifer.

Soil cores and extracted pore waters should be analyzed for leachate, indicator parameters (which after five years should be known). Additional analyses will depend upon the amount of soil and pore water available, pore water extraction techniques, soil analyses methods, leachate quality etc., and cannot be determined at this time.

5.5 MITIGATION AND CONTINGENCY STRATEGIES

5.5.1 Mitigation

Any existing boreholes and monitors penetrating to the lower till or bedrock aquifer in the landfill area should be sealed prior to construction of the landfill. This aspect is discussed in more detail in Appendix A.

Strategies to manage potential chloride impacts on bedrock ground waters should be investigated. These could include:

- alternate disposal techniques for chloride and related salts,
- recovery of chloride and related salts for alternate uses,
- monitoring leachate salt quality, reassessment of potential impacts once actual quality is known and implementation of mitigation or contingency actions based on this assessment, when and if warranted.

Should leachate quality monitoring identify quality of potential concern for other contaminants, then strategies should be developed to modify treatment processes and solidification formulations to improve leachate quality for these contaminants. Exclusion of certain wastes could also be considered.

5.5.2 Contingencies

Contingency strategies are actions that could be employed should monitoring indicate a pending ground water impact not previously predicted.

Should contamination of shallow ground water occur due to upward leachate diffusion and should this shallow ground water have the potential to migrate off-site, the ground water could be collected in the buffer zone for treatment as discussed in Chapter 3.

Should the above lead to contamination of surface waters in the swales of the cover; the surface water could be collected and treated before release off-site.

Should contaminants be found to be migrating through the soils underlying the landfill at rates and concentrations that could potential impact the aquifer, the leachate collection system could be activated. This would reverse the direction of ground water flow back towards the landfill, thus containing further leachate migration except by the very slow process of diffusion. Note that if the leachate collection system is activated strategies for treating the leachate should be in place. As well, methods of reducing leachate production through reduced infiltration should be developed. These could include for example installing a synthetic barrier system near the surface of the present cover.

Note that although leachate collection systems are not normally considered contingencies, the setting of the Preferred Site and the landfill design proposed by OWMC are not anticipated to require leachate collection. Thus activation of this system is considered a contingency in this case, not mitigation.

5.6 DECOMMISSIONING AND END LAND USE

Upon closure of the facility, the landfill will remain. Decommissioning strategies for the landfill should include development of a closure and post-closure plan as per regulations in place at the time. These should include:

(1) development of a post closure ground water monitoring program, and

(2) contingency plans for dealing with leachate, should activation of the collection system ever be required after closure.

Current Ministry of the Environment (MOE) policies and guidelines state there should be no sensitive land use, (e.g., residential and commercial buildings) on or within 30 metres of a closed landfill (Ministry of the Environment, 1986). It is noted that OWMC has made a commitment to preserve their facility in government control of some form in perpetuity (Monenco, 1987) which is consistent with the MOE policies.

6.0 REFERENCES

Gartner Lee Limited (GLL), 1987a:

Site Assessment - Phase 4B: Geology, Hydrogeology, and Geotechnics, Baseline Conditions; Report prepared for the Ontario Waste Management Corporation. (Draft).

Gartner Lee Limited (GLL), 1987b:

Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Hydrogeologic Input to Landfill Design: Report prepared for the Ontario Waste Management Corporation (Draft).

Gartner Lee Limited (GLL), 1987c:

Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Geotechnical Input to Facilities Design; Report prepared for the Ontario Waste Management Corporation (Draft).

Gartner Lee Limited (GLL), 1987d:

Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Potential Impacts on Ground Water from the Landfill; Report prepared for the Ontario Waste Management Corporation (Draft).

Gartner Lee Limited (GLL), 1987e:

Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Potential Impact on Ground Water from the Central Operating Area; Report prepared for the Ontario Waste Management Corporation (Draft).

Ministry of the Environment. 1983:

Ontario Drinking Water Objectives.

Ministry of the Environment. 1986:

Guidelines for Land Use on or Near Landfills and Dumps. Policy #07-07-01. MOE Policy Manual. Environmental Approvals and Land Use Planning Branch, Ontario Ministry of the Environment, March 28, 1986.

Ministry of the Environment. 1987:

Guidelines for the Decommissioning of Sites in Ontario. Draft version, May 27, 1987.

M.M. Dillon Limited 1987:

Site Assessment Phase 4B: Surface Water. Report prepared for the Ontario Waste Management Corporation (Draft).

APPENDIX A

MITIGATION OF ABANDONED BOREHOLES, GROUND WATER MONITORS AND WATER WELLS

TABLE OF CONTENTS

A1.0 INTRODUCTION 1

A2.0 METHODOLOGY 3

A3.0 EXISTING REGULATIONS GOVERNING WELL ABANDONMENT 4

A4.0 OVERVIEW OF SITE CONDITIONS 6

A5.0 BOREHOLES TO BE SEALED 7

A6.0 OVERDRILLING PROCEDURES 12

A7.0 TYPE OF GROUT MATERIAL 14

A8.0 EMPLACEMENT OF GROUT 16

A9.0 CONCLUSIONS AND RECOMMENDATIONS 20

A10. REFERENCES 22

LIST OF FIGURES

FIGURE A1 SITE PLAN AND BOREHOLE LOCATIONS 2

FIGURE A2 SCHEMATIC CROSS-SECTION SHOWING MONITOR AND BOREHOLE DEPTHS 8

FIGURE A3 CONSTRUCTION DETAILS OF MONITORS 10

FIGURE A4 BOREHOLE PLUGGING PLAN/RECORD 17

FIGURE A5 GROUTING OVERDRILLED BOREHOLES USING TREMIE PIPE 18

A1.0 INTRODUCTION

A large number of boreholes exist on the Ontario Waste Management Corporation (OWMC) Preferred Site, most of which are test holes drilled by Gartner Lee Limited during the hydrogeological evaluation of the site. Most of the test holes contain PVC monitors that are currently being used to collect ground water data. Other boreholes include several sealed test holes and three domestic water wells. Some of the boreholes are located in future designated landfill or central operating area, while others are located in the 50 m perimeter buffer zone (Figure A1).

The OWMC site was selected, among other reasons, because of the protective 35 m thick low-permeability clay-till layer that overlies the regional bedrock aquifer. This layer will minimize the seepage of contaminants at the surface from reaching the bedrock. Some of the boreholes, and more significantly the monitor pipes, located in the proposed landfill and operational areas, are drilled through this protective layer and penetrate the underlying bedrock aquifer. Therefore in areas where facilities will be built on top of these monitors, they provide potential hydraulic conduits or short circuits for the seepage of contaminants through the protective clay-till aquitard to the bedrock. These boreholes and monitors must be properly sealed before the OWMC facility is constructed and operational.

It is important to establish protocols to ensure that these holes are completely and permanently sealed to preclude the contamination of the bedrock aquifer. At a minimum, the protocols must meet the existing Ontario regulations concerning the abandonment of wells. Given the proposed use of the site, the protocols outlined in this document have been developed to be even more stringent than the existing regulations.

The objectives of this report are to determine which boreholes require sealing and to determine protocols describing proper techniques and grouting material for sealing these boreholes.

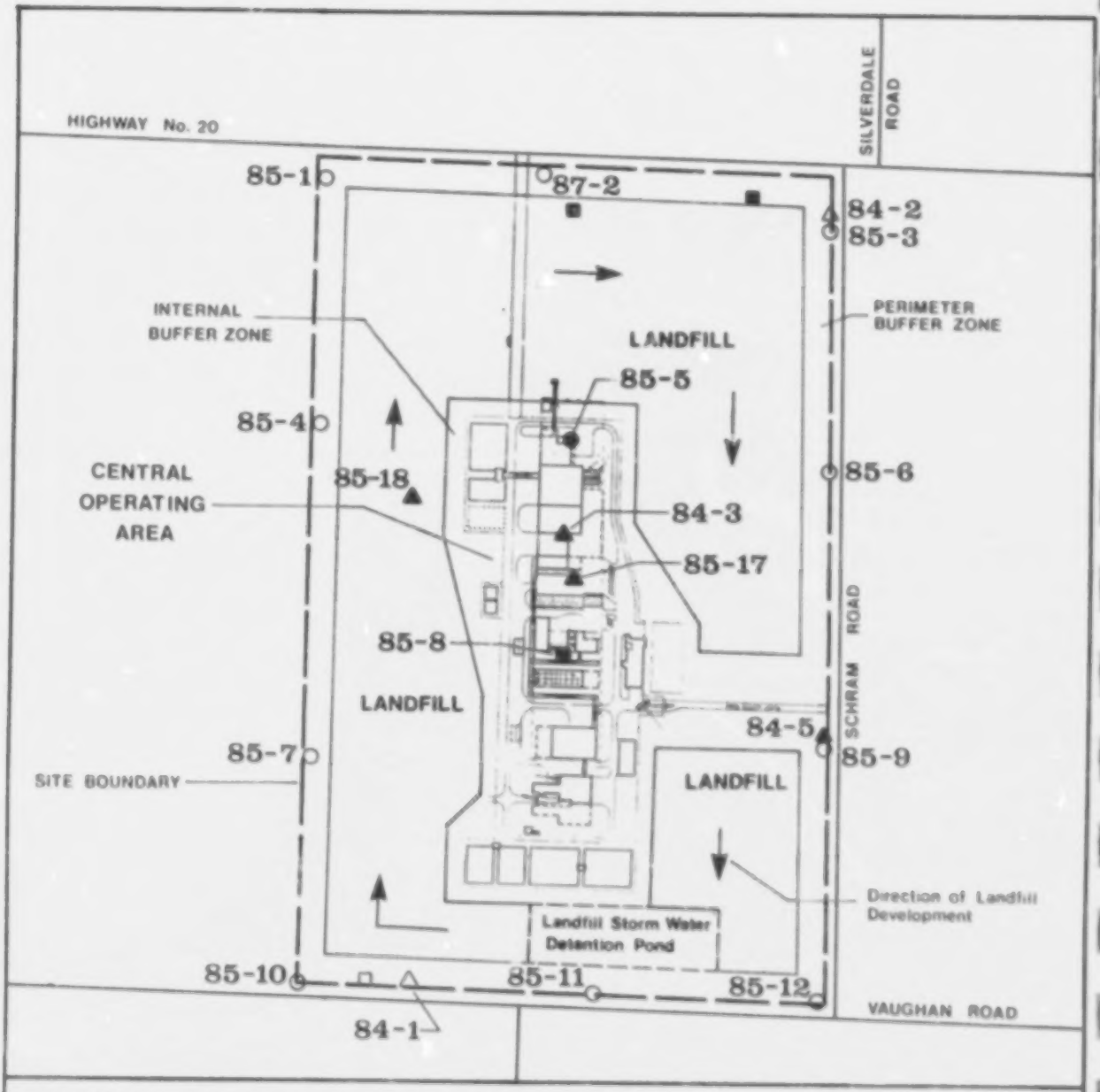


FIGURE A1: Site Plan and Borehole Locations

LEGEND

Boreholes to be Sealed

- ● Monitor Group
- ▲ Test Borehole
- ■ Water Well (Bedrock)

Boreholes Not to be Sealed

- ○ Monitor Group
- △ Test Borehole
- □ Water Well (Overburden)

N

0 Metres 200

NOTE: (1) Details on the Central Operating Area are Provided in the Design and Operations report (Monenco, 1987).

(2) Landfill Storm Water Detention Pond Location Approximate Only.

A2.0 METHODOLOGY

A review was made of existing regulations of the Ontario Ministry of the Environment (MOE) and the U.S. Environmental Protection Agency (U.S. EPA) regarding the abandonment of water wells, monitor wells, and oil/gas wells.

As well, a literature search was done for references on well abandonment techniques and grout materials. The main references used in preparation of these protocols were several texts and papers dealing with the abandonment and grouting of water wells (Driscoll, 1986; Campbell and Lehr, 1973; Gass, Lehr and Heiss, Jr., 1977), general grouting practices (Bowen, 1981) and the compatibility of grouts with hazardous wastes (Spooner et al, 1984).

An outside expert, Dr. H. C. Eaton of Scientific Waste Strategies, Inc., (SWS), was consulted for advice on the proper grout material to be used in sealing the monitors, and on the appropriateness of the grout used in the boreholes already sealed.

A3.0 EXISTING REGULATIONS GOVERNING WELL ABANDONMENT

The protocols described in this report are consistent with, and more stringent than, the MOE and the U.S. EPA guidelines. The basic goal behind most existing well abandonment regulations is the restoration, as nearly as possible, of the subsurface hydrogeological conditions that existed prior to drilling the wells. The following protocols for sealing the boreholes on the OWMC site have been designed to meet these criteria specifically for the hydrogeological and geochemical conditions at the site.

The regulations regarding well abandonment in Ontario are given under the MOE Water Resources Act, Ontario Regulation 612/84, Section 21 (Appendix B). The Regulation does not differentiate between water wells and monitoring wells. The Regulation places legal responsibility for the plugging of abandoned wells onto the well owner: "When a well is to be abandoned, it shall be plugged with concrete or other suitable material so as to preclude the vertical movement of water or gas in the well between aquifers or between an aquifer and the ground surface" (Ministry of the Environment, 1984).

The Regulation specifies the conditions under which a well owner must abandon and plug a well. The MOE Water Resources Act Regulation 612/84 also authorizes the MOE to direct that a well be plugged should the well be constructed in contravention of any of the provisions of the Regulation, including improper spacing from sources of contamination.

The MOE has also published a brochure of guidelines (Ministry of the Environment, 1986; Appendix C), for the plugging of water wells, but these are not part of MOE Water Resource Act Regulation 612/84. The U.S. EPA (1977) has outlined similar practices and techniques for well abandonment (Appendix D). Both the MOE and U.S. EPA guidelines specify the preparations for abandonment, abandonment methods for different types of water wells in different formations and hydrogeological conditions, and the type and placement of grout.

The construction of the monitors and the sealing of the test boreholes at the OWMC Preferred Site, in particular the composition of the grout used and the method of grouting, were done according to the existing MOE and U.S. EPA protocols. These methods are described in Gartner Lee Associates Limited (1985) and Gartner Lee Limited (1987).

A4.0 OVERVIEW OF SITE CONDITIONS

The hydrogeology and geochemistry of the Preferred Site is described in detail in Gartner Lee Limited (1987). The following is only an overview.

The geology of the site consists of about 35 m of clay/silt aquitard overlying a dolostone bedrock aquifer. The upper about 5 m of the aquitard is weathered with an average hydraulic conductivity of 10^{-8} m/s. The remainder of the aquitard is unweathered with a very low hydraulic conductivity of 3×10^{-10} m/s. The hydraulic conductivity of the bedrock is about 2×10^{-4} m/s in the upper 6 m; below this zone the conductivity ranges between 2×10^{-9} to 2×10^{-5} m/s. Ground water flow is downward through the overburden aquitard and lateral in the bedrock aquifer.

The ground water chemistry at the site is significant from the point of view of its compatibility with potential grout types used to seal the boreholes, and therefore affects the selection of the grout material. Certain types of cement, for example, deteriorate with time when in contact with waters high in sulphate content.

The ground water chemistry at the OWMC site is characterized by very high total dissolved solids in the shallow ground waters above 9 m depth. The sulphate in these shallow waters ranges between 5000 and 9500 mg/L. Sulphates are incompatible with many types of cements. Below 9 m depth, the total dissolved solids are much lower, about 1000 mg/L, and the sulphate between 400 and 800 mg/L. The ground waters in the shallow bedrock contain total dissolved solids in the range of 2000 to 3000 mg/L and sulphate in the range of 1370 to 1650 mg/L.

A5.0 BOREHOLES TO BE SEALED

A total of 135 boreholes have been drilled on the OWMC Preferred Site. These include 125 Gartner Lee Limited monitors at 12 locations (85-1 to 85-12), 7 exploratory boreholes (84-1 to 85-5, 85-17 and 85-18) and 3 domestic water wells (Figure A1).

The boreholes to be sealed (or re-sealed) on the OWMC site are at locations 85-5, 85-8, 84-3, 84-4, 84-5, 85-17 and domestic water wells #1 and #2 (Figure A1). All of these boreholes except 84-5 are within the proposed central operating area or landfill area. Although borehole 84-5 is not within the landfill or central operating area it is sufficiently close to the entrance road, which is a potential spill area, that re-sealing is recommended. Also, borehole 85-18 may require re-sealing depending on its depth with respect to the final landfill base at this location. All other monitors, boreholes and wells on-site are in the 50 m perimeter buffer zone and should not require sealing. If migration of contaminants from the landfill to the buffer zone should occur in the future, then the potential for these monitors and boreholes to act as conduits to the bedrock should be assessed at that time.

Both of the water wells to be sealed do not have MOE well records. Well #1 is a drilled bedrock well of unknown depth (but >40 m) located about 25 m inside the proposed landfill area on the north side of the site (Figure A1). Well #2 is a drilled bedrock well about 37 m deep. It is not within the proposed landfill area, but is recommended for sealing due to its close proximity to the landfill edge and lack of construction information.

Pertinent details of the boreholes that require sealing are tabulated in Appendix E. These monitors and boreholes are shown schematically in cross-section relative to the local geology in Figure A2. At locations 85-5 and 85-8 there are 5 and 11 monitors, respectively. These monitors must be overdrilled and the holes infilled with an appropriate grout mixture to be described in Section A6. Boreholes 84-3, 84-4, 84-5, 85-17 and 85-18 contain no monitors, and were sealed immediately after drilling with a grout composed of Portland cement Type 10 (ASTM Type 1) and 3-4% bentonite. Although this formulation is consistent with that recommended by the U.S. EPA

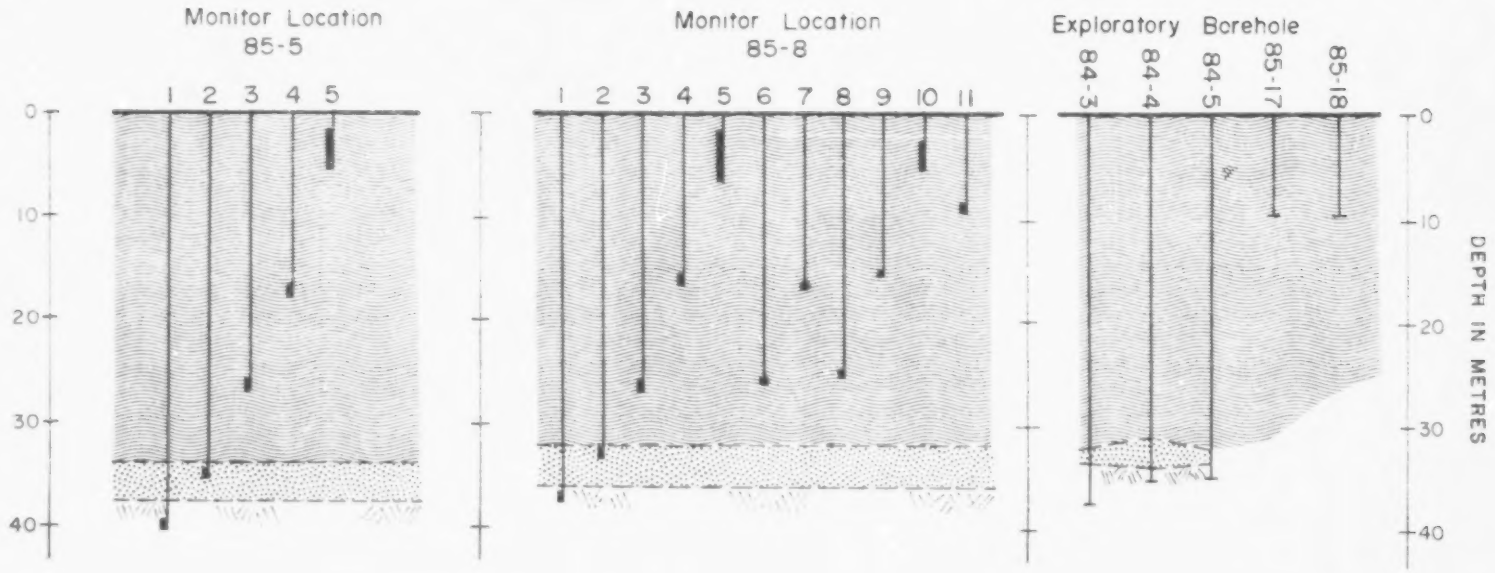


FIGURE A2

Schematic Cross-Section Showing Monitor and Borehole Depths

LEGEND

Clay and Silt

Silt and Sand Till

Aquitard

Dolostone Bedrock Aquifer

PVC Monitor

Pneumatic Monitor

Exploratory Borehole (No Monitor, Sealed)

Gartner Lee Limited

Project 87-577

(Appendix D), this grout mixture has since been deemed potentially inappropriate due to its shrinkage properties, by Dr. H.C. Eaton, SWS (Appendix F). Dr. Eaton recommends that these boreholes be overdrilled and re-grouted by a more suitable grout. The rationale for this recommendation is explained further in Section A6.

The ground water monitors at locations 85-5 and 85-8 consist of standard piezometers and standpipes and pneumatic piezometers. The construction details of these monitors are shown in Figure A3. The standard monitors are constructed of 19 mm or 51 mm diameter, schedule 80 PVC pipe and screen. The annulus around the screens was backfilled with silica sand to about 0.3 m above the top of the screen. A bentonite seal about 3 m or more thick was installed directly above the sand pack. The annular space above the bentonite seal was backfilled to within about 0.5 m of the ground surface with a grout mix consisting of 1.5 - 3.0% bentonite, 40-60% cement (Canadian Type 10 (ASTM Type 1) Portland) and 40-60% water.

The pneumatic piezometers consist of a transducer made of plastic and rubber materials connected to the surface with two polyethylene tubes. The transducer is packed in silica sand and the borehole is backfilled with bentonite and grout in a similar manner to the standard monitors (Figure A3).

Boreholes 84-4 and 85-18 are 35.5 m and 10.0 m deep, respectively, and are located in the future landfill area. Since the landfill excavation will be 15 m deep, the upper half of 84-4 and all of 85-18 will probably be removed in the preparation of the site. The excavation operations may disturb the cement-bentonite seals. It may therefore be advantageous, depending on access, to seal these holes after the landfill excavation has been prepared.

Boreholes 84-3, 84-4, 84-5, 85-17, and 85-18 have not been tied into OWMC's survey and at present have no marker to indicate their location. These boreholes must be located prior to facility construction. To find them in the field, the approximate location should be determined based on original field notes. The ground surface in the area should then be scraped with a backhoe to confirm the location of the existing borehole cement plug, which begins at 1 to 3 m below the surface.

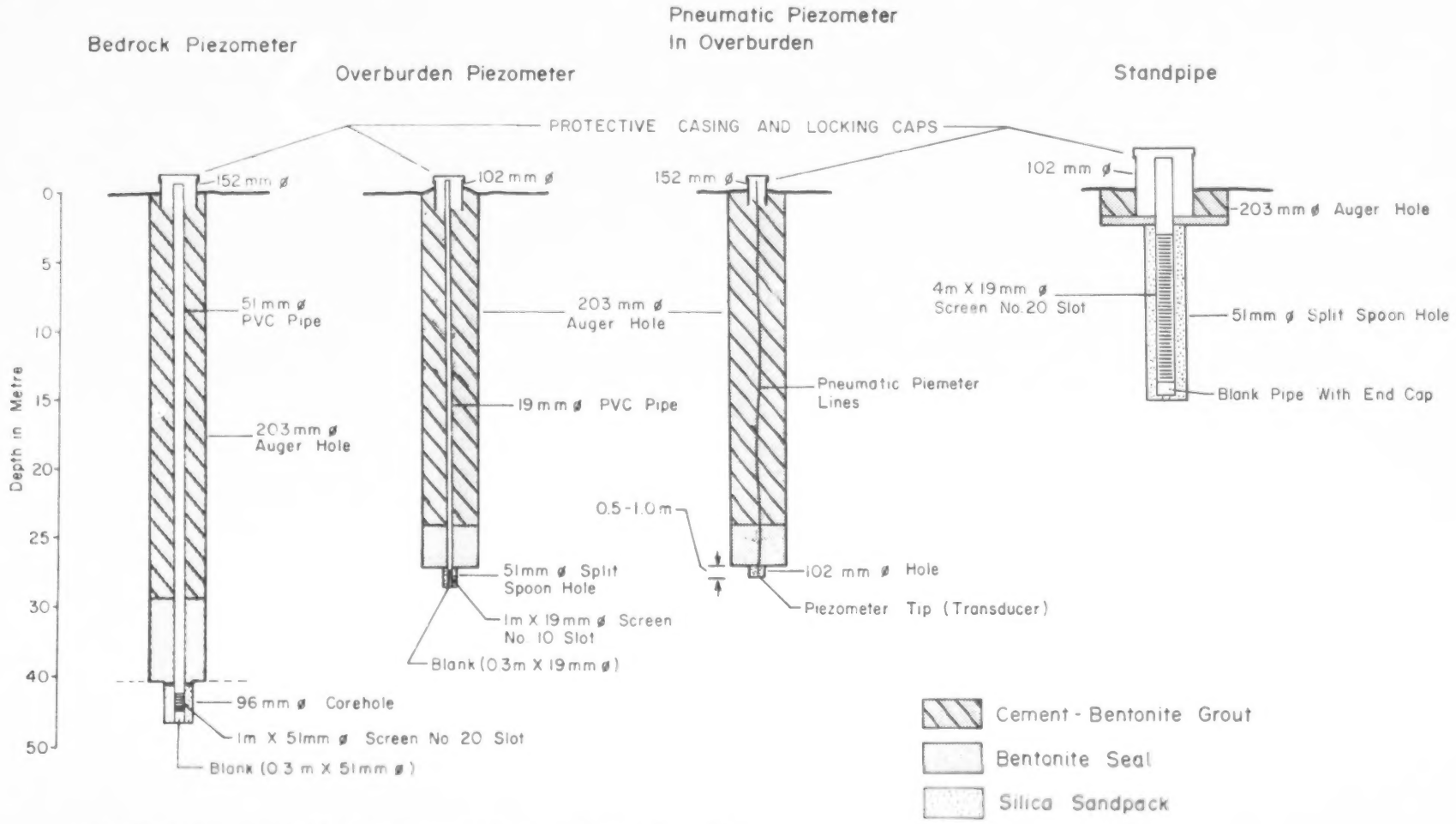


FIGURE A3: Construction Details Of Monitors

Particular attention should also be given to protecting all monitors from damage during site construction and operation. Monitors at locations 85-2 and 85-9 are close to the proposed service corridor and entrance roadway and are therefore likely most susceptible to this kind of damage. Placement of berms and construction of ditches within the 50 m buffer zone may also lead to monitor damage. Should any monitor be damaged beyond repair it should be sealed immediately.

A6.0 OVERDRILLING PROCEDURES

A water well driller with a mud rotary rig should be contracted to overdrill the boreholes to be sealed and perform the grouting operation. He should be experienced in borehole sealing procedures and must have the equipment necessary to overdrill the boreholes, mix the grout and inject the slurry.

Ideally, the overdrilling technique should be capable of following the original borehole to the bottom with a minimum of misalignment. This may be difficult because the original auger holes are probably not completely vertical or straight. In addition, the existing cement-bentonite in the holes may be harder than the surrounding clay and till, which may cause the bit to deflect into the host (in-situ) material.

It is recommended that prior to overdrilling the boreholes, one of the monitors be dug up with a backhoe to check the condition of the cement-bentonite backfill. This will be of use to determine the relative hardness of the backfill to that of the natural clay-till and to check the integrity of the existing seals.

Several overdrilling techniques are possible, one of which may be more appropriate depending on field conditions. One option would be to use a large-diameter tricone bit to overdrill the plug and monitor. The boreholes are about 200 to 250 mm in diameter (Appendix E). Appropriate bit sizes larger than the hole diameter must be used to allow for misalignment of the existing borehole with the overdrilled borehole.

Another option would be to wash and drive large-diameter steel casing over the existing cement-bentonite plug to the bottom of the hole, and then to drill out the plug and monitor inside the casing.

For the monitors, a small-diameter drag or wing bit attached to AW (44 mm OD) drill rods could be dropped inside the monitor and seated below the bottom of the monitor. These rods would be temporarily left in the hole to serve as a guide for a large auger or special tricone bit that would then over drill the borehole.

The depth and diameter of the boreholes should be checked before the start of drilling (Appendix E). Overdrilling should proceed to the total depth of the borehole. A fine mesh screen should be installed on the drilling rig to filter out the fine PVC material cuttings to prevent clogging of the mud pump.

The MOE and U.S. EPA state that the material used to seal an aquifer be disinfected before emplacement. We recommend disinfection procedures be done for those boreholes and monitors that intersect or come close to the aquifer (i.e. the bedrock or the lower silt and sand till. Although the U.S. EPA specifies a chlorine-based compound for disinfection, we recommend the use of disinfectant that does not introduce chlorine to the ground water system because this may lead to a false indication of leachate presence.

A7.0 TYPE OF GROUT MATERIAL

Advice on the proper grout mixture to be used in sealing the boreholes was obtained from Dr. H.C. Eaton, a materials scientist with SWS, Baton Rouge, Louisiana. SWS is an environmental consulting firm with particular expertise in the area of solidification/stabilization of hazardous wastes. A report by SWS with recommendations on the acceptable grout mixtures is provided in Appendix F.

The MOE and U.S. EPA recommend ASTM Type 1 (Canadian Type 10) Portland cement for grouting monitoring wells. This is the type of cement presently used to seal boreholes and monitoring wells on-site. SWS, however, advises against the use of this cement because of potential shrinkage, upon hardening. This may cause the cement plug to pull away from the borehole wall and create a potential conduit. At OWMC's Preferred Site this shrinkage factor may not be significant due to the inward squeeze of the borehole walls on the grout plug caused by the plasticity of the native clayey soil. However, there is no fool-proof field method for determining if this is the case. Given the uncertainty involved and the proposed use of the site, the use of a different grout formulation is recommended as a justified precaution.

SWS describes three possible grout formulations: Type K expansive cement, a proprietary formulation by a specialized grouting firm or Five Star Special Grout 150. For reasons discussed below, we recommend the use of either the first or the second grout types.

The first grout type consists of Type K expansive cement as the primary component, with a small amount of bentonite (3 - 4% by weight) added to increase the plasticity. The use of an expansive Type K cement minimizes the possibility of a shrinkage annulus forming around the hardened grout plug through which contaminant transport could occur.

The second option is a grout provided by a reputable special grouting formulation firm such as Haliburton Well Services or Dowell-Schlumberger. This would be a proprietary formulation, which means that the grout composition would be undisclosed. An

advantage of using special grouting firms, however, is their experience in mixing grouts, supervising borehole sealing operations and making on-site decisions as required by field conditions.

The third option is Five Star, Special Grout 150, manufactured by U.S. Grout Corporation. This is a non-shrinking, but non-expansive grout formulation. Because of its non-expansive properties, this grout is not considered to be as appropriate as the first two grout types.

A8.0 EMPLACEMENT OF GROUT

Calculations should be made beforehand as to the correct amount of grout slurry necessary to fill the entire hole. An additional amount of grout should be prepared to allow for borehole volume variations and possible fluid loss to the bedrock formation, in boreholes 84-3, 84-4, 85-5-1, 85-8-1, and water well #1. A Borehole Plugging Plan/Record sheet (Figure A4) should be used to record calculations.

The grout must be placed in the borehole using the tremie method, which is illustrated schematically in Figure A5. The tremie pipe must have a minimum inside diameter of 51 mm (U.S. EPA, 1977). The grout should be introduced at the bottom of the hole and placed progressively upward to the top of the borehole. This is to minimize dilution or bridging of the grout slurry. The tremie pipe should initially extend to the bottom of the hole and during the grouting, the bottom of the tremie pipe should always be submerged a metre or so below the grout level. As the grout level rises, the tremie pipe should be withdrawn at about the same rate. The drilling fluid will rise up the hole as it is displaced by the heavier grout slurry.

To ensure a satisfactory seal, the grout should be placed in one continuous operation, before setting begins. A suitable pump with sufficient air or water pressure should be used to force the grout into the borehole rapidly and to minimize the chance of leaving voids in the grout. Gravity installation of the grout with or without the aid of a tremie pipe should not be used.

Verification must be made to ensure that the borehole is completely filled and that no jamming or bridging of the grout material has occurred. During injection of the grout, the depth to the top of the grout should be measured with a weighted line to ensure that filling is preceding and to direct when the tremie pipe should be raised. To ensure that the hole is filled, the grout must flow out of the borehole at the surface. In addition, verification should be made that the volume of grout placed in the borehole at least equals the volume of the empty hole.

Gartner Lee Associates Limited

FIGURE A4

BOREHOLE PLUGGING PLAN / RECORD

PROJECT: _____ BOREHOLE: _____ BY: _____

SITE: _____ LOCATION: _____ CONTRACTOR: _____

CLIENT: _____ DATE: _____ DRILLER: _____

VOLUME CALCULATION

1.	Hole Depth (m)	= _____		
2.	Bit Diameter (mm)	= _____		
3.	#2 x 1.1 (mm)	= _____	=	Estimated Hole Diameter
4.	#3 ÷ 1000 (m)	= _____	=	Estimated Hole Radius in Meters
5.	$(\#4)^2$ x Pi(m^2)	= _____	=	Hole Volume/meter (m^3/m)
6.	#1 (m) x #5 (m^3/m)	= _____	=	Hole Volume (m^3)
7.	Additional %	= _____	=	Volume for mixing (m^3)
8.	Total volume	= _____	=	Volume for mixing (L) = _____

MIXING QUANTITIES/STAGE	TOTAL	STAGE 1	STAGE 2	STAGE 3
9. #8 Volume Grout (L)	_____	_____	_____	_____
10. Required Cement (bags)	_____	_____	_____	_____
11. Required Water (L)	_____	_____	_____	_____
12. Required Bentonite (L)	_____	_____	_____	_____

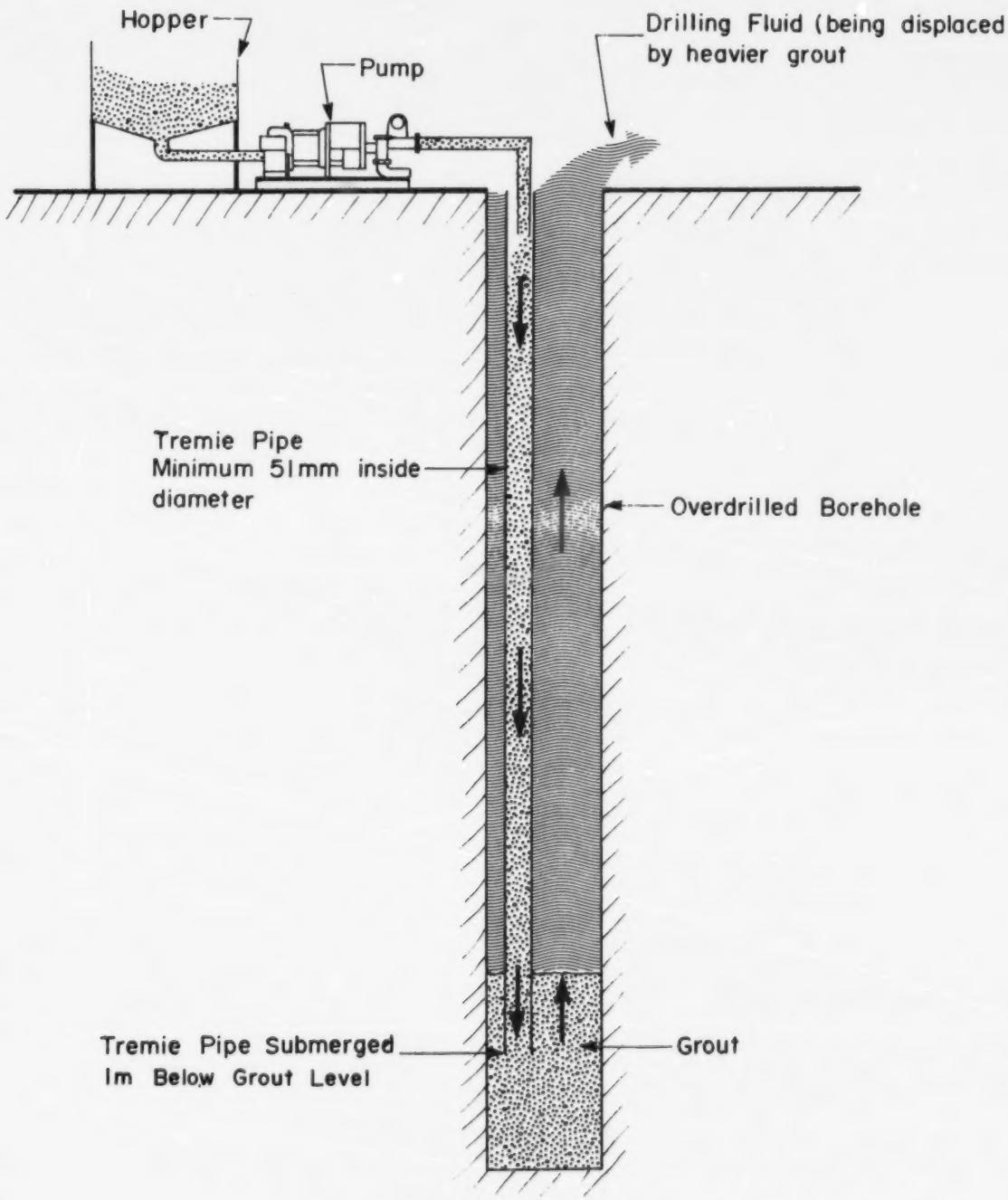
PUMPING QUANTITIES/DEPTH				
13. Time Initial Circulation Achieved	_____	_____	_____	_____
14. Start Mixing Time	_____	_____	_____	_____
15. End Mixing Time	_____	_____	_____	_____
16. Start Pumping Time	_____	_____	_____	_____
17. End Pumping Time	_____	_____	_____	_____
18. Volume Grout Pumped	_____	_____	_____	_____
19. Depth of Rods	_____	_____	_____	_____
20. Return Achieved (Yes / No)	_____	_____	_____	_____

DESCRIPTION OF UPPER METRE

COMMENTS

WEATHER

FIGURE A5
Grouting Overdrilled Boreholes Using Tremie Pipe



Not To Scale

The consistency of the grout should be checked before injection into the hole and at the completion of grouting when the borehole is full. A small sample of the grout slurry should be taken from each hole to confirm the setting characteristics of the mix. The pump, the tremie pipe and the hoses should be flushed with clean water after each batch of grout is pumped into place.

If the flow of grout is interrupted, the tremie pipe must be raised above the grout level until all air and drilling fluid have been displaced. The tremie pipe must be removed soon after grout emplacement to allow the grout to fill the hole made by this pipe.

A few days after emplacement of the grout the borehole should be inspected and refilled if settling of the grout has occurred.

A9.0 CONCLUSIONS AND RECOMMENDATIONS

1. Several boreholes located in the landfill or central operating area on the OWMC Preferred Site provide potential hydraulic conduits for the seepage of contaminants through the protective clay-till aquitard to the underlying bedrock aquifer. These must be properly plugged before the OWMC treatment facility is constructed and operational.

2. It is important to establish protocols to ensure that these holes are completely and permanently sealed to preclude the contamination of the bedrock aquifer. The protocols described in this report are consistent with, and more stringent than, those specified by the MOE and the U.S. EPA.

3. Monitors at locations 85-5 and 85-8 must be overdrilled and the holes filled with an appropriate agent.

4. Boreholes 84-3, 84-4, 84-5, 85-17, and 85-18 contain no monitors and were sealed with a cement-bentonite mixture consistent with that required by the U.S. EPA but are deemed potentially inappropriate due to its shrinkage properties by SWS. These boreholes should be overdrilled and re-grouted with a more suitable grout.

5. Two drilled bedrock water wells (wells #1 and #2 on Figure A1) of unknown construction located just inside or adjacent to the proposed landfill area on the north side of the site should be sealed. Prior to sealing, the depth and condition of the well should be checked and all objects removed (i.e. pumps).

6. A water well driller should be contracted to overdrill the boreholes and perform the grouting operation. He should be experienced with the proposed borehole sealing procedures and must have the equipment necessary to overdrill the boreholes, mix the grout and inject the slurry.

7. There are two recommended grout types for sealing the boreholes. The first is a mixture of Type K expansive cement as the primary component, with a small amount of bentonite (3 - 4% by weight) added to increase the plasticity. Type K cement is recommended because it expands during setting and therefore the possibility of shrinkage annulus around the hardened grout is minimal. The second recommended option is a grout provided by a specialized grouting firm. Although this mix would be proprietary, the advantage of a special grouting firm is their experience in mixing grouts and supervising borehole sealing operations.

8. The grout must be placed in the borehole using the tremie method. Gravity installation of the grout with or without the aid of a tremie pipe must not be used.

9. A grouting expert should be present in the field to supervise the procedure of mixing and placing the grout in the boreholes. This will be to ensure that the grout material is of proper and consistent composition and that the borehole is properly sealed.

A10. REFERENCES

Bowen, R., 1981.
Grouting in Engineering Practice. Applied Science Publishers Ltd.

Campbell, M.D. and Lehr, J.H., 1973.
Water Well Technology. National Water Well Association. McGraw-Hill Book Company.

M.M. Dillon Limited, 1986.
OWMC Treatment Facility, Process Area Report, Engineered Landfill. November, 1986.

Driscoll, F.G., 1986.
Ground Water and Wells, Second Edition. Johnson Division, St. Paul, Minn.

Gartner Lee Associates Ltd., 1985.
Site Selection Process, Phase 4A, Technical Appendix LF-9C: Geologic, Hydrogeologic, and Geotechnical Considerations. Report prepared for OWMC, Project 85-S18.3., September 1985.

Gartner Lee Ltd., 1987.
Site Assessment Phase 4B, Geology, Hydrogeology and Geotechnics, Baseline Conditions, Volumes 1, 2 and 3.

Gass, T.E., Lehr, J.H. and Heiss, Jr., H.W., 1977.
Impact of Abandoned Wells on Ground Water. U.S. Environmental Protections Agency, EPA-600/3-77-095.

Ministry of the Environment, 1984.
Ontario Water Resources Act, O. Reg. 612/84, s.21.

Ministry of the Environment, 1986.

About Water Wells and Ground Water Supplies, Recommended Methods for Plugging Abandoned Water Wells. September, 1986.

Spooner, P.A., Hunt, G.E., Hodge, V.E., and P.M. Wagner, 1984.

Compatibility of Grouts with Hazardous Wastes. U.S. EPA-600/2-84-015.

U.S. Environmental Protection Agency, 1977.

Manual of Water Well Construction Practices. EPA-570/9-75-001.

APPENDIX B

ONTARIO WATER RESOURCES ACT
SECTION 21

138 St. Clair Avenue West
Suite 100
Toronto, Ontario
M4V 1P6

138 avenue St. C
Bureau 100
Toronto (Ontario)
M4V 1P6

ONTARIO WATER RESOURCES ACT

Sections 21, 22, and 44 of the Ontario Water Resources Act as amended pertaining to water wells and proclaimed in force November 1, 1984.

87/03/19

(*d*) where no well pit exists, the air vent shall extend above the land surface a distance sufficient to prevent the entry of flood water from any anticipated flooding in the area but not less than thirty centimetres;

(*e*) the open end of the air vent shall be shielded and screened in a manner sufficient to prevent the entry of any materials into the well; and

(*f*) if natural gas is present, the air vent shall be extended to the outside atmosphere in a manner that will safely disperse all gases. O. Reg. 612/84, s. 18.

TESTING OF WELL YIELD

19.—(1) When the yield of water from a well is tested and the pumping equipment used will permit the measurement of water levels in the well,

(*a*) the water level in the well shall be measured and recorded on the well record in Form 9 immediately before commencement of pumping and every fifteen minutes thereafter during pumping;

(*b*) the water level in the well shall be measured by means of a tape, air line or electrical device;

(*c*) water shall be pumped from the well continuously for at least one hour; and

(*d*) the rate of pumping during the test shall be recorded on the well record in Form 9.

(2) If water cannot be pumped from the well continuously for one hour, there shall be recorded on the well record in Form 9,

(*a*) the reason pumping was discontinued;

(*b*) the rate of pumping and the length of the pumping period; and

(*c*) the water level measurements made.

(3) When the yield of water from a well is tested and a bailer or other pumping equipment is used that will not permit the accurate measurement of water levels in the well,

(*a*) the water level in the well shall be measured and recorded on the well record in Form 9 immediately before commencement of bailing or pumping, upon termination of bailing or pumping and every fifteen minutes thereafter for at least one hour;

(*b*) the water level in the well shall be measured by means of a tape, air line or electrical device;

(*c*) water shall be bailed or pumped from the well continuously for at least one hour; and

(*d*) the rate of bailing or pumping during the test shall be recorded on the well record in Form 9.

(4) If water cannot be bailed or pumped from the well continuously for one hour, there shall be recorded on the well record in Form 9,

(*a*) the reason pumping or bailing was discontinued; and

(*b*) the rate of bailing or pumping and the length of the bailing or pumping period. O. Reg 612/84, s. 19.

CONTAMINATION CONTROL

20.—(1) Where a well is constructed and mineralized water is encountered, the person constructing the well shall immediately notify the well owner that the condition exists.

(2) Where a well is constructed and natural gas is encountered, the person constructing the well shall immediately notify the well owner and the Director that the condition exists.

(3) The well owner shall maintain the well at all times after the completion date in a manner sufficient to prevent the entry into the well of surface water or other foreign materials. O. Reg. 612/84, s. 20.

ABANDONMENT

21.—(1) When a well is to be abandoned, it shall be plugged with concrete or other suitable material so as to preclude the vertical movement of water or gas in the well between aquifers or between an aquifer and the ground surface.

(2) The well owner of a new well that is dry shall forthwith abandon the well.

(3) The well owner of a well that is not being used or maintained for future use as a well shall forthwith abandon the well.

(4) The well owner of a well that is producing salty, sulphurous or mineralized water or water that is otherwise not potable shall forthwith abandon the well.

(5) The well owner of a well in which natural gas is encountered or a well that is constructed in contravention of any provision of this Regulation dealing with the location or spacing of wells, the methods and materials used in the construction of wells or the standards of well construction shall forthwith abandon the well if directed to do so by the Director. O. Reg. 612/84, s. 21.

APPENDIX C

MOE RECOMMENDED METHODS
FOR PLUGGING ABANDONED
WATER WELLS

ABOUT WATER WELLS AND GROUND-WATER SUPPLIES (Rev. Sept. 1986)

RECOMMENDED METHODS FOR PLUGGING ABANDONED WATER WELLS

Introduction

Unplugged, abandoned water wells may constitute a hazard to public health and safety. The plugging of these wells will eliminate the hazard and preserve and protect our ground-water resources. Abandoned dug and bored wells that may have deteriorated gradually over the years are of particular concern because of their large diameter.

Ontario Regulation 612/84 places legal responsibility for the plugging of abandoned wells onto the well owner. Section 21 states: "When a well is to be abandoned, it shall be plugged with concrete or other suitable material so as to preclude the vertical movement of water or gas in the well between aquifers or between an aquifer and the ground surface." The conditions under which a well owner must abandon and plug a well are: (1) a new well which is dry (2) a well which is not being used and which is not being maintained for future use (3) a well which is producing salty, sulphurous or mineralized water or water that is unpotable The regulations also authorize the Ministry of the Environment to direct that a well be plugged should the well encounter natural gas, or be constructed in contravention of any of the provisions of the regulations including improper spacing from sources of pollution.

The main reasons for plugging a well are to: (1) eliminate the physical hazard (2) prevent ground-water contamination (3) conserve the yield and maintain water levels in the aquifers* (4) prevent the intermingling between desirable and undesirable

---

*An aquifer is a water-bearing, saturated geological unit or formation that will yield water to wells. Aquifers may occur in the overburden or in the bedrock. A loosely packed gravel is a good aquifer, a silt or a very fine sand is a poor aquifer and fractured rock may be a good or poor aquifer.

NOTE: In this publication: (1) Cement is a mixture of portland cement and water. (2) Concrete is a mixture of water, portland cement, and sand or gravel. (3) Bentonite is a commercially available colloidal clay in powder or granular form. It can be used in thickening drilling muds, as an additive to cement slurries and as a sealant because of its special gel-forming and swelling properties when mixed with water.

quality waters The basic concept is to restore as near as possible subsurface conditions to what they were before the well was installed.

To insure that the plugging is effective requires that suitable materials are used and that their placement is appropriate to the local well and ground conditions. The purpose of this article is to provide guidance in the selection and placement of plugging materials relative to various types of wells in different geologic and hydrologic conditions.

Whether you plug your own well or whether you hire a licensed well contractor, you should be aware that the plugging of some wells will be difficult because of the depth of the well, the hydrostatic head conditions (e.g., flowing well) or the complex nature of the geological formations. In these circumstances it may be advisable to hire a well contractor. The availability of proper equipment and his knowledge of construction techniques and local geological conditions would be valuable to the achievement of a proper well abandonment. The improper use of placement techniques could result in failure to achieve the plugging objectives.

Your Regional Groundwater Evaluator or Regional Water Well Inspector may also be contacted for advice and information on well construction and local ground conditions. (Addresses of regional offices are listed at the back of this Facts sheet.) He may be able to provide you with a copy of the Water Well Record for the well you plan to seal. This record will provide a description of the construction details of the well and will be of assistance to you or to the well contractor you select in determining the best method to seal your well. Records for most wells drilled since 1949 are on file in the regional offices of the Ministry of the Environment.

Sealing Wells in Unconsolidated Formations

A well completed in a sand or gravel aquifer in the overburden and having a satisfactory formation seal on the outside of the casing can be adequately sealed by backfilling the cased portion of the well with a sequence of plugs consisting of cement grout, concrete, bentonite, clay and sand and gravel as shown in Figure 1.

If there are other producing wells located nearby in the same water-bearing formation, care must be taken in the selection and placement of sealing materials so that they will not move laterally outward through the aquifer and affect the water quality of these wells (ie. cause them to produce cloudy water). The use of cement or concrete in the aquifer is discouraged for this reason.

The most suitable fill material to place opposite a water-bearing formation (see Figure 1) is a clean, disinfected sand or gravel. A bored well will most likely have gravel in the wellbore, placed there by the well contractor during well construction.

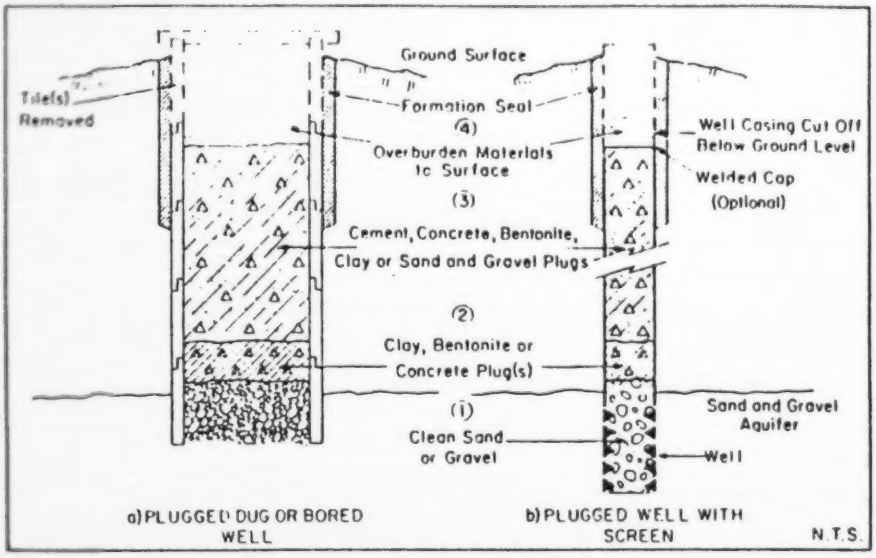


FIGURE I. SEALING OVERBURDEN WELLS

These materials should extend into the cased portion of the well and be capped with a clay slurry, bentonite or concrete plug. The remainder of the cased well may be entirely filled to surface with cement, concrete, bentonite, clay, or with alternating plugs of sand and gravel and cement or clay. Removal of the upper portion of the well casing and backfilling is good practice and is recommended (Figure 1). A capping device may be attached to the top of the casing as an added protection. These procedures will prevent the vertical movement of waters within the cased portion of the well.

Should the well's formation seal not be adequate, then the total withdrawal of the well casing is desirable since it will assure the outward progression of the plugging materials into the adjacent formations thereby providing a better seal and effectively preventing the vertical movement of water. In many cases it is not always possible to pull the casing. Therefore, the only practical solution is to excavate around the casing and cut off the casing a safe distance below ground surface or remove sufficient tiles in the case of a bored well. Next, place a clay slurry, bentonite or concrete plug at the base of the excavation, sealing the top of the cased portion of the well and any open annulus outside the well casing. Backfill the remainder of the excavation with overburden materials to ground surface. This is only done after the lower portion of the well has been adequately sealed. Clay is especially suitable for sealing the upper portion of large-diameter wells.

Sealing Wells in Rock Formations

Wells that penetrate limestone or other fractured rock formations should preferably be filled with concrete or cement to assure the permanence of the seal. The use of clay or sand in the uncased portion of such wells is not desirable because fine-grained fill material may be displaced by the flow of ground water through crevices or fractures.

Alternate plugs of coarse sand and gravel and concrete may be used in deep wells or in wells where the vertical movement of water between fractures within the wellbore will not affect the quality or quantity of well water in nearby producing wells. It may be necessary in the placement of these materials to set a clay or a fine sand seal ahead of the concrete as in the case of wells in unconsolidated formations to increase the effectiveness of the seal material. Wherever possible, the placement of cement or concrete opposite a water-producing horizon is to be avoided.

The upper 3 to 6 metres of borehole in the rock, just below the bottom of the well casing, should be filled with cement or concrete to provide an effective plug or seal against the possible vertical movement of surface waters into the bedrock. Cement, concrete, bentonite, clay, or sand and gravel with occasional cement or clay plugs may be used to fill the cased portion of the well.

Sealing Wells Obtaining Water From More Than One Aquifer in the Bedrock

A special case is the sealing of wells encountering more than one aquifer. These wells should be sealed to prevent the movement of ground water between aquifers (see Figure 2).

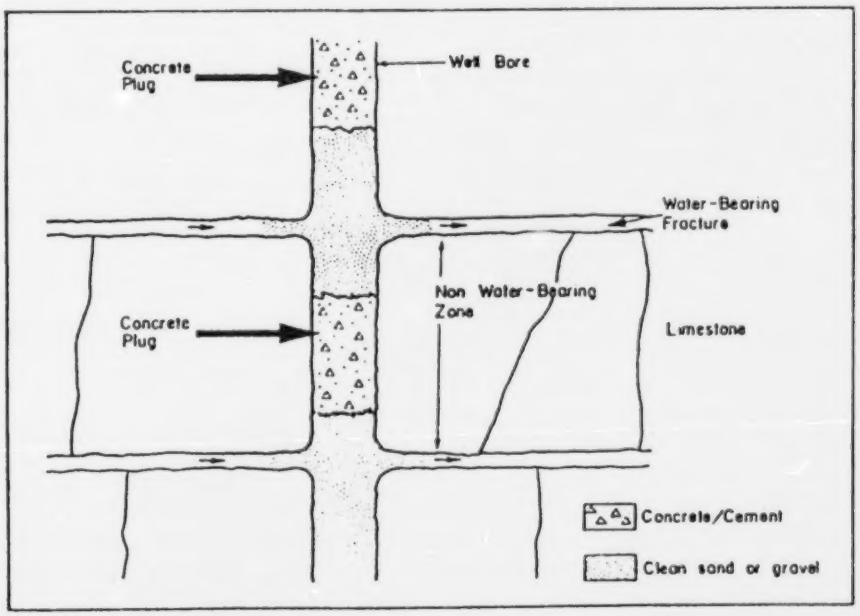


FIGURE 2. SEALING OPEN HOLE IN BEDROCK

If there are no water-bearing zones within an extensive portion of the wellbore, then filling the wellbore with cement, concrete or alternate layers of these materials and coarse sand and gravel is satisfactory. Concrete and cement are preferable because they will penetrate and fill the voids and fractures in the wall of the borehole and will provide the most effective seal against the movement of waters. If alternating cement or concrete plugs and sand and gravel are set to control the ground-water movement in the wellbore, then the concrete plugs must be placed in known non-producing, competent horizons or if the location of the non-producing horizons are not known then at sufficiently frequent intervals to ensure an effective seal.

Plugging Wells With Artesian Flow

The sealing of flowing wells or wells that have a movement of water between aquifers requires special techniques and an experienced well contractor because the rate of flow and pressure heads of ground water may be such as to make the normal sealing techniques using gravity placement of cement, concrete and clay impractical. In the case of uncontrolled flow, the drilling of a relief well may be necessary to relieve the pressure in the aquifer and to lower the water level in a flowing well below ground level, thereby, allowing plugging to proceed normally. Control over the free flow from a well may sometimes be obtained through the use of plugs, well packers, heavy drilling mud or by extending the well casing above ground level and above the artesian head in the well. Pumping a high density cement slurry through a grout pipe placed near the bottom of the casing may balance the artesian head and may permit control of the well to be regained. Control of the flow can only be maintained where there is an effective formation seal between the well casing and the well bore otherwise a "breakout" or the leakage of ground water around the outside of the casing may occur with serious results.

It is important to remember in the control of flowing wells to prevent: 1) groundwater movement between formations since this could result in the pressurization of shallower water-bearing zones 2) uncontrolled flow of water at surface from the well casing or from around the outside of the well casing.

Well Abandonment Records

Before the plugging equipment is removed from the site, the exact location of the abandoned well or hole should be accurately established with respect to permanent reference points such as a building, so that the property owner will have a permanent record of the location. The materials used to plug the well and the details of the plugging procedure should also be recorded. This record of information will provide a good reference should problems occur in the future. Your Regional Groundwater Evaluator should also be notified of the abandonment.

Environment Ontario Regional Office staff will be pleased to answer any questions on well plugging and can be contacted at the locations listed below:

Northwestern Region (807-475-1205)
435 James St. S., 3rd Floor
Thunder Bay, Ontario P7C 5G6

Northeastern Region (705-675-4501)
199 Larch St., 11th Floor
Sudbury, Ontario P3E 5P9

Southwestern Region (519-661-2200)
985 Adelaide St. S.
London, Ontario N6E 1V3

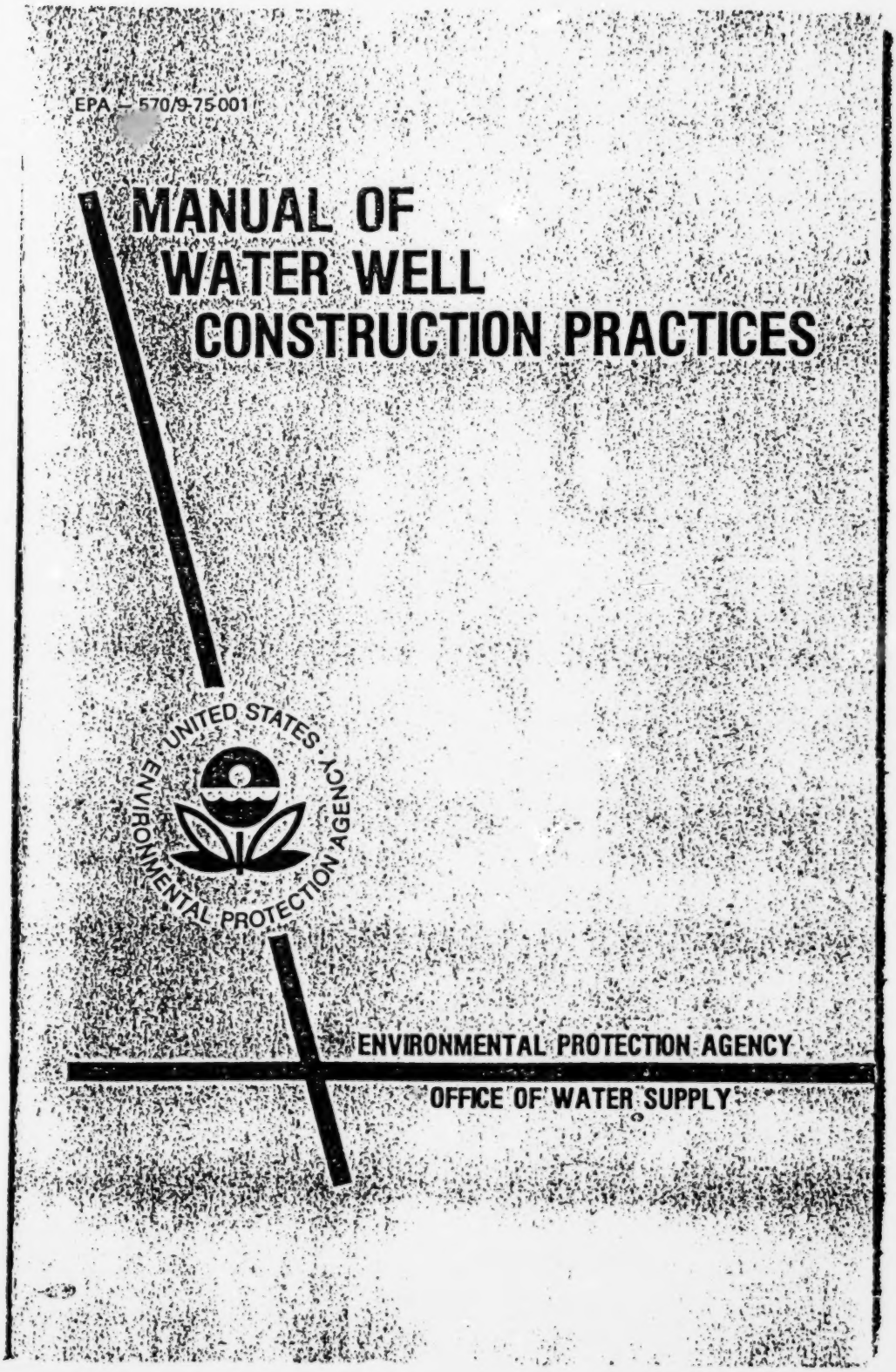
West Central Region (416-521-7702)
119 King St. W., 12th Floor
Hamilton, Ontario L8N 3Z9

Central Region (416-424-3000)
7 Overlea Blvd., 4th Floor
Toronto, Ontario M4H 1A8

Southeastern Region (613-549-4000)
133 Dalton Ave.
Kingston, Ontario K7L 4X6

APPENDIX D

U.S. EPA PROTOCOLS FOR
GROUTING AND WELL ABANDONMENT


EPA – 570/9-75-001
MANUAL OF
WATER WELL
CONSTRUCTION PRACTICES
UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER SUPPLY

a. Casing Furnished and Installed .....Unit Price
b. Pitless Unit Furnished and Installed .....Lump Sum
c. Pressure Testing .....Lump Sum

Article 48
Well Grouting

PREAMBLE

Grouting consists of filling an annular or other space with an impervious material. The reasons for grouting are: 1) protection of the aquifer, or aquifers, including the prevention of water movement between aquifers, for purposes of maintaining quality or preserving the hydraulic response of the producing zone(s), and 2) protecting the well against the entry of unwanted water from the surface or a subsurface zone.

A third, and sometimes important purpose of grouting is to protect the casing. This may be necessary to guard against attack by corrosive waters, or where special assurance of structural integrity is desired. A satisfactory grouting program must result in complete envelopment of the casing.

In determining the specific grouting requirements of a well at a designated site, consideration must be given to existing surface conditions, especially the location of sources of pollution, and to subsurface geologic and hydrologic conditions. To protect against contamination or pollution by surface waters or shallow subsurface waters (such as effluent from septic tanks) the annular space shall be sealed to whatever depth is necessary to protect the well. This may be as little as 10 feet or more than 100 feet, depending on conditions.

Formations which yield polluted water or water of an undesirable quality must be adequately sealed off to prevent pollution or contamination of the overlying or underlying waterbearing zones. To accomplish this the annular space shall be grouted from at least 10 feet above to 10 feet below the interval from which such polluted or mineralized water is being produced.

In general, positive emplacement of grout by tremie, pumping, or pressure is strongly recommended for all wells where the grout is to be placed under water or where the void space to be filled is not easily accessible from the surface.

Centralizers may be required in certain zones to prevent the casing from contacting the wall of the bore hole, or to maintain a minimum annular space where a complete seal is imperative.

Where grounting is required the OWNER and/or appropriate regulatory agency should be notified in advance of the work. Prior to grouting the annular space should be flushed to assure that the space is open and ready to receive the sealing material. Grouting should be done in one continuous operation in which the annular space is filled. Where pours exceed 100 feet, the collapse strength of the casing should be checked prior to grouting. Grout containing cement should be entirely placed before the occurrence of

the initial set. Again, caution is required in deep seals. It is essential that the grout always be introduced at the bottom of the space being grouted. This is to avoid segregation or bridging of the grout materials and to exclude foreign substances. The grout may be forced into the annular space by suitable pumps or by air or water pressure.

Under certain conditions placement by gravity or by means of dump bailers is practical and satisfactory. Gravity installation without the aid of a tremie or grout pipe should *not* be used unless the interval to be grouted can be seen clearly and is dry. In no instance should it be done beyond 30 feet of depth. Only by visual observation can there be assurance that grout introduced in this way is properly and uniformly distributed.

Where a tremie pipe is used there should be a minimum annular opening of two inches (5.08 cm) between the outer surface of the inside casing and the inside surface of the external casing or borehole. The minimum size tremie pipe should be one and one-half inches in diameter. Where concrete grout is used the minimum size tremie pipe should be a nominal one and one-half inches in diameter.

The method used shall be optional with the CONTRACTOR, provided there is no conflict with requirements for construction practice set forth in these standards. Cement-based materials are the most commonly used grouts. Neat cement (cement and water), sand-cement, and concrete (cement, sand and coarse aggregate) are readily available already mixed or they can be easily mixed at the site. Neat cement and sand cement grouts are effective and permanent sealing materials and are preferred. Concretes are more applicable where the space to be filled is substantial and warrants the saving gained from the use of less cement.

The usefulness of clay as a sealant in well construction is limited to instances where drying out and washing away cannot occur. Clays are usually not suitable as sealants under the following conditions:

1. When sealants will be in contact with aquifers.
2. Wherever structural strength or stability of the sealant is required.
3. Wherever the sealant might dry out.
4. Wherever flowing or moving water might break down the sealant.

For the use of clay in well abandonment operations see Article 56.

There are presently no fool-proof field tests that can be performed to determine if a proper grout seal has been achieved. All five of the most commonly used field tests, e.g., the static water level test, the water temperature test, the water chemical composition test, the pressure test and the cement bond log test, etc., have imperfections. However, under controlled conditions, the latter two tests may indicate in a general way the nature of the grout seal and its probable effectiveness. Considerable research is needed in this area of technology. Suffice it here to state that the proper choice of any field method depends solely on a clear understanding of the specific hydrogeologic conditions and the construction techniques and materials employed in the grouting operation.

It should be noted that in situations where the effectiveness of the grouting procedure is of extreme importance, it is recommended that the grouted zone either be pressure tested or an appropriate cement bond log run. The interpretation of the data from such tests must be made by a log analyst with considerable experience with such data.

Grouting Materials to be Used

48.100–000–000. ***Concrete Grout.*** A mixture of Portland cement (ASTM C150), sand, coarse aggregate and water in the proportion of at least five (5) bags of cement per cubic yard of concrete to not more than seven (7)* gallons of clean water per bag of cement (one cubic foot or 94 pounds) shall be used. The use of special cements, bentonite to reduce shrinkage or other admixtures (ASTM C494) to reduce permeability, increase fluidity, and/or control time of set, and the composition of the resultant slurry must be approved by the OWNER or PROJECT REPRESENTATIVE.

48.200–000–000. ***Sand Cement Grout.*** A mixture of Portland Cement (ASTM C150), sand and water in the proportion of not more than two parts by weight of sand to one part of cement with not more than seven (7)* gallons of clean water per bag of cement (one cubic foot or 94 pounds) shall be used. The use of special cements, bentonite to reduce shrinkage or other admixtures (ASTM C494) to reduce permeability, increase fluidity, and/or control time of set, and the composition of the resultant slurry must be approved by the OWNER or PROJECT REPRESENTATIVE.

48.300–000–000. ***Neat Cement Grout.*** A mixture of Portland cement (ASTM C150) and not more than seven (7)* gallons of clean water per bag (one cubic foot or 94 pounds) of cement, shall be used. The use of special cements, bentonite to reduce shrinkage or other admixtures (ASTM C494) to reduce permeability, increase fluidity, and/or control time of set, and the composition of the resultant slurry must be approved by the OWNER or PROJECT REPRESENTATIVE.

Methods of Installation of Grout

48.010–000–000. ***Bailer Dumping.*** Grout material shall be placed by lowering the grout material to the bottom of the hole in a bailer, and dumping (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The bailer shall not be dumped more than one foot from the bottom of the hole, and a time of no more than ten minutes shall elapse between dumps in a single plug. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type III-minimum 36 hours.

---

* EPA recommends not more than 6 gallons of clean water per bag of cement. It should be noted that better flow characteristics can be produced through the use of cement additives, thereby eliminating the weaking effects which may result from the use of excess water.

48.020–000–000. *Gravity Filling Without Tremie Method.* Grout material shall be uniformly poured into the annular space without the aid of a tremie or grout pipe (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). This method shall be employed only where the interval to be grouted is clearly visible from the surface and is dry. Maximum allowable depth to bottom of grout interval shall be 30 feet.

48.030–000–000. *Tremie Method.* Grout material shall be placed by tremie pouring (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The tremie method shall only be used where there is a minimum annular space of 3 inches (7.62 cm) between the outside surface of the inside casing and the inside surface of either the external casing or the borehole. The minimum size tremie pipe utilized shall be 2 inches (5.08 cm) inside diameter. Where concrete grout is used the minimum size tremie pipe used shall be three inches (7.62 cm) inside diameter. When making a tremie pour, the tremie pipe shall be lowered to the bottom of the zone being grouted, and raised slowly as the grout material is introduced. The tremie pipe shall be kept full continuously from start to finish of the grouting procedure, with the discharge end of the tremie pipe being continuously submerged in the grout until the zone to be grouted is completely filled. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type III-minimum 36 hours.

48.040–000–000. *Positive Placement—Exterior Method.* Grout material shall be placed by a positive displacement method such as pumping or forced injection by air pressure (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). Grout shall be injected in the annular space between the inner casing and either the outer casing or the borehole. The annular space must be a minimum of 1½ inches (3.81 cm) for sand-and-cement or neat cement grout, and not less than three times the size of the largest coarse aggregate used. The grout pipe shall extend from the surface to the bottom of the zone to be grouted. The grout pipe shall have a minimum inside diameter of one inch for sand-cement or neat cement grout. It shall have a minimum diameter of 1½ inches (3.8 cm) for concrete grout. Grout shall be placed, from bottom to top, in one continuous operation. The grout pipe may be slowly raised as the grout is placed but the discharge end of the grout pipe must be submerged in the emplaced grout at all times until grouting is completed. The grout pipe shall be maintained full, to the surface, at all times until the completion of the grouting of the entire specified zone. In the event of interruption in the grouting operations, the bottom of the pipe should be raised above the grout level and should not be resubmerged until all air and water have been displaced from the grout pipe and the pipe flushed clean with clear water. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type II-minimum 36 hours.

48.050–000–000. *Positive Placement—Interior Method—Two Plug.* Grout shall be placed by the two-plug cementing method (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). The first spacer plug, which shall be a drillable plug such as a plaster-type material, shall then be inserted and the casing capped. A measured volume of grout shall be pumped in which shall be of sufficient quantity to grout the casing in place. The casing shall then be uncapped, the second plug shall be inserted, and the casing recapped. A measured volume of water slightly less than the volume of the casing shall then be pumped into the casing until the second plug is pushed to the bottom of the casing, expelling the grout from the casing up and into the annular space. The water in the casing shall be maintained constant to prevent backflow until the grout has set. Pressure shall be maintained for a minimum of 24 hours or until such time as a sample of the grout indicates a satisfactory set. Cement grout shall be used for this procedure with a minimum annular space thickness of 1½ inches (3.81 cm) completely surrounding the casing. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type III-minimum 36 hours. Concrete grout cannot be used with this method.

48.060–000–000. *Positive Placement—Interior Method—Upper Plug.* Grout shall be placed by the upper plug casing method (after water or other drilling fluid has been circulated in the annular space sufficient to clear obstructions). A measured quantity of grout, sufficient to grout the casing in place, shall be pumped into the capped casing. Because this grout is in direct contact with the drilling fluid there will be a narrow zone of weak grout between the drilling fluid and the good grout. The casing shall be uncapped, and a drillable plug, constructed of plastic or other suitable material shall be inserted on top of the grout and the casing recapped. A measured volume of water, equal to the volume of the casing, shall be pumped into the casing, forcing the plug to the bottom of the casing and expelling the grout into the annular space surrounding the casing. Utilizing this method the weak grout zone at the interface of grout and drilling fluid will not be located at the critical position at the bottom of the casing. The water in the casing shall be maintained under pressure to prevent back flow until the grout has set. Pressure shall be maintained for a minimum of 24 hours or until such time as a sample of the grout indicates a satisfactory set. Neat cement or sand-cement grout shall be used for this procedure, with a minimum annular space opening of 1½ inches (3.8 cm) completely surrounding the casing. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type III-minimum 36 hours. Concrete grout cannot be used with this method.

48.070–000–000. *Positive Placement—Interior Method—Capped Casing.* Grout shall be placed by pumping or air pressure injection through the grout pipe installed inside the casing from the casing head to a point 5 feet (1.5 m) above the bottom of the casing (after water or other drilling

fluid has been circulated in the annular space sufficient to clear obstructions). The grout pipe shall extend airtight, through a sealed cap on the casing head of the well casing. The casing head shall be equipped with a relief valve and the drop pipe shall be equipped at the top with a valve permitting injection. The lower end of the drop pipe and the casing shall be open. Clean water shall be injected down the grout pipe until it returns through the casing head relief valve. The relief valve is then closed and injection of water is continued until it flows from the bore hole *outside* of the casing to be grouted in place. This circulation of water is intended to clean the hole and condition it to better take the grout. Without significant interruption, grout shall be substituted for water and, in a continuous manner, injected down the grout pipe until it returns to the surface outside of the casing. A small amount of water, not to exceed seventeen gallons per hundred lineal feet (30 m) of 2 inch (5.08 cm) droppipe may be used to flush the grout pipe, but pressure shall be maintained constant on the inside of the grout pipe and the inside of the casing until the grout has set. Pressure shall be maintained for at least 24 hours, or until such time as a sample of the grout indicates a satisfactory set. Neat cement or sand-cement grout shall be used for this procedure with a minimum annular space of 1½ inches (3.8 cm) completely surrounding the casing. Curing time before construction may be resumed: Portland Cement Type I-minimum 72 hours; Type III-minimum 36 hours. Congrete grout cannot be used with this method.

48.080–000–000. ***Continuous Injection Method.*** Grout shall be placed by the float sh[illegible]ntinuous injection method, (after water or other drilling fluid has been c[illegible]culated in the annular space sufficient to clear obstructions). The bottom of the casing shall be fitted with a suitable drillable float shoe equipped with a back pressure valve. Tubing or pipe shall be run to the float shoe to which it shall be connected by a bayonet fitting, left hand thread coupling, or similar release mechanism. Water or other drilling fluid shall be circulated through the tubing and up through the annular space outside the casing. When the annular space is clean and open, grout shall be pumped down the pipe or tubing and forced by continual pumping out into the annular space surrounding the casing. Pumping shall continue until the entire zone to be grouted is filled. The grout pipe shall then be detached from the float shoe and raised to the surface for flushing. After the grout has set the float shoe, back pressure valve, and any concrete plug remaining in the bottom of the casing shall be drilled out. A neat cement or sand-cement grout shall be used for this procedure with a minimum annular space of 1.5 inches completely surrounding the casing. Curing time required before construction may be resumed shall be 72 hours for Type I Portland Cement and 36 hours for Type III. Concrete grout cannot be used with this method.

48.090–000–000. ***Grout Displacement Method.*** The hole shall be filled with the estimated volume of grout required for the purpose intended. The casing fitted at the bottom with a drillable back pressure valve, metal

plate, or similar seal shall be lowered through the grout to the bottom of the hole. If necessary to maintain the bottom of the casing at the bottom of the hole, the casing shall be filled with water, or drilling fluid, and in some cases by applying a load on the bottom with drill pipe. The load shall be maintained until the grout has set, after which the bottom plug is drilled out and the well deepened. Use of this method is limited to wells not more than 100 feet in depth.

LOCATION OF GROUT

48.001–000–000. ***Surface Formation Seal.*** The annular space to be grouted, and surrounding the permanent well casing at the upper terminus of the well, shall be not less than a nominal 2 inches. The length of the grout seal shall be whatever is necessary to prevent the entrance of surface water or undesirable subsurface water into the well. In any circumstance, the length of seal shall not be less than the minimum specified in the state or locally applicable construction code.

The entire space to be grouted must be open and available to receive the grout at the time the grouting operation is performed. If a section of larger pipe (conductor pipe) is installed to keep the entire space open (in caving materials), this larger pipe must be removed, as the grout is installed, from the zone where the seal is required.

The effective length of grout seal (for sanitary purposes) shall be that distance measured from the deepest limit of the seal up to the depth of frost penetration. If a pitless adapter or unit is to be installed, the upper limit of the seal shall be one foot below the field connection of the adapter or unit.

48.002–000–000. ***Bottom Seal Grouting.*** Grout shall be placed in the annular space surrounding the bottom of the casing by the method specified. The space shall be grouted to the extent indicated in Figure 1.

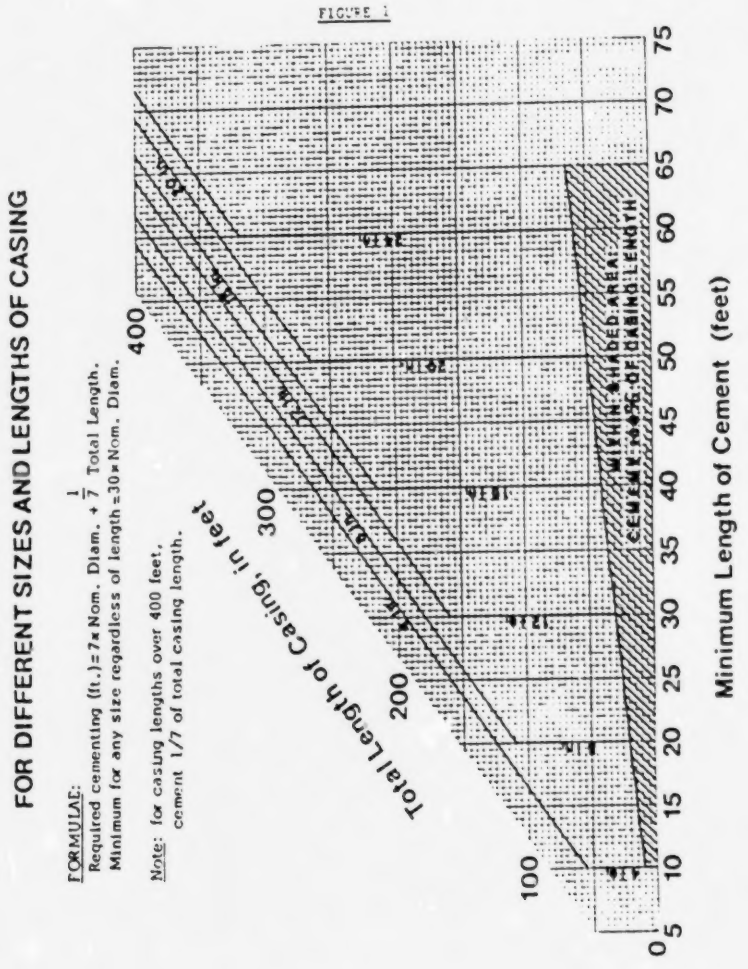
48.003–000–000. ***Selected Interval Grouting.*** All zones containing water of unsuitable quality shall be grouted from a point at least 5 feet (1.5 m) below, to a point at least 5 feet (1.5 m) above the unsuitable zone. The annular space surrounding the casing between grouted zones shall be filled with sand or other suitable granular material.

48.004–000–000. ***Continuous Grouting.*** Grout shall be placed in the annular space surrounding the casing by the method specified. Grouting shall be continuous from the bottom of the permanent casing to the land surface; or, where a filter pack has been installed, from the top of the pack (following development) to the land surface; or, where a well screen only has been installed, from a point 5 feet (1.5 m) above the screen to the land surface. When a pitless adapter or unit is to be installed, the grout shall extend from such depth to within one foot of the field connection of the adapter or unit.

CENTRALIZERS

48.000–100–000. ***Contractor's Choice.***

FIGURE 1



48.000–200–000. *Centralizers at Bottom of Hole.* Centralizers shall be required at the bottom of the casing only.

48.000–300–000. ***Centralizers at Bottom of Hole and other Critical Points.*** Centralizers shall be attached to the bottom of the casing at other critical grouting points such as zones of unsuitable water quality.

48.000–400–000 ***Centralizers at 25 Feet Intervals.*** Centralizers shall be spaced at intervals not greater than 25 feet (7.5 m).

Geophysical Logging for Cement Bond

48.000–010–000. ***Acoustic-Sonic Cement Bond Log.*** Upon completion of the cure of the grout, normally 72 hours but varying with materials and additives used, an acoustic-sonic cement bond log shall be run in the borehole from the top to bottom to determine the quality of grout emplacements. The report of this test shall be delivered to the OWNER or his representative for his permanent record. The interpretation of such log shall be made by a log analyst of demonstrable experience with such data.

Pressure Testing of Grouting Seal

48.000–001–000. ***Pressure Testing of Grouting Seal.*** Pressure testing of the grout seal shall be employed following the appropriate time for curing of the grout according to all appropriate provisions in this Article. A pressure of 7 to 10 pounds of air per square inch is to be maintained within the well, without the addition of more air, for a period of not less than one hour. Any loss of air shall be construed as indicating a defective seal. To correct such a defect, the OWNER shall require the CONTRACTOR to make the necessary repairs by re-cementing and pressure testing at 15 psi for one hour.

Method of Payment for Grouting

48.000–000–100. ***Method of Payment.***

Option A (Lump Sum): All of the work performed under this Article (48) shall be paid for as a lump sum.

Option B (Time and Materials): All of the work performed under this Article (48) shall be paid for on the basis of the price bid for well construction equipment per hour plus materials at cost plus percent of add-on bid.

Option C (Unit Price): All of the following work performed under this Article (48) shall be paid for at the unit price bid per hour for well construction equipment plus the cost of any materials and/or subcontracted services at the invoice price plus percent of add-on bid.

a. Furnish and Install Grout ..... Unit Price per Sack
b. Cement Bond Log ..... Unit Price per Foot
c. Pumping Grout Service ..... Lump Sum
d. Pressure Testing of Grouting ..... Lump Sum

techniques and methods shall be as prescribed in *Standard Methods for the Examination of Water and Waste Water*, a joint publication of the American Public Health Association, American Water Works Association, and Water Pollution Control Federation. All samples shall be appropriately identified as to geographic location, date, time, method of collection, point of collection, water bearing formation(s), depth and diameter of well, water level and yield, and shall include the name of the sample collector, CONTRACTOR, driller and OWNER.

METHOD OF PAYMENT
FOR WATER SAMPLES AND ANALYSES

55.000–000–010. ***Method of Payment.***

Option A (Lump Sum): All of the work performed under this Article (55) shall be paid for as a lump sum.

Option B (Time and Materials): All of the work performed under this Article (55) shall be paid for on the basis of the price bid for well construction equipment per hour plus materials at its cost plus per cent of add-on bid.

Option C (Unit Price): All of the following work performed under this Article (55) shall be paid for at the unit price bid per hour for well construction equipment plus the cost of any materials and/or subcontracted services at the invoice price plus percent of add-on bid:

a. Water Analyses .....Unit Price/Test Series

Article 56
Permanent Well and Test Hole Abandonment

PREAMBLE

Unsealed abandoned wells constitute a hazard to public health, safety, welfare, and to the preservation of the ground water resource. The sealing of such wells presents a number of problems, the character of which depends upon the construction of the well, the geological formations encountered, and the hydrologic conditions. To seal an abandoned water well properly, several things must be accomplished: (1) elimination of a physical hazard; (2) prevention of ground water contamination; (3) conservation of yield and maintenance of hydrostatic head of aquifers; and (4) prevention of the intermingling of desirable and undesirable waters.

The basic concept governing the proper sealing of abandoned wells is the restoration, as far as feasible, of the geohydrologic conditions that existed before the well was drilled and constructed, for an improperly abandoned well might serve as an uncontrolled invasion point for contaminated and polluted water. Any well that is to be permanently abandoned should be completely filled in such a manner that vertical movement of water within the well bore, including vertical movement of water within the annular space surrounding the well casing, is effectively and permanently prevented and the water is permanently confined to the specific zone in which it originally

occurred. If all these objectives can be accomplished, all the rules for sealing wells heretofore presented will be fulfilled.

To seal an abandoned well properly, the character of the ground water must be considered. If the ground water occurs under unconfined or water-table conditions, the chief problem is that of sealing the well with impermeable material so as to prevent the percolation of surface water through the original well opening, or along the outside of the casing, to the water table. If the ground water occurs under confined or artesian conditions, the sealing operation must confine the water to the aquifer in which it occurs—thereby preventing loss of artesian pressure by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that in the aquifer which is to be sealed.

Preparation For Abandonment

Strong efforts should be made to remove all materials from a well which may hinder its proper abandonment. This is especially important where specified zones must be sealed.

If a screen has been installed in the well by telescoping, its recovery is usually possible by installing a string of fishing casing from the top of the well to a sand hitch placed close to the bottom of the screen. Following the setting of the sand hitch, a lifting force, applied either by mechanical or hydraulic jacks, or multiple pulling lines from the casing reel of the drilling machine, will usually withdraw the screen from the well.

In recovering steel casings extending to the surface, the least expensive and least hazardous method is to apply a lifting force to the casing by the use of jacks, or with the drilling machine, or with the two in combination. Still more effective is the use of a jarring head applied at the top of the casing string and used in combination with lifting devices.

Maximum recovery is usually obtained by using a trip-type casing spear actuated by a fishing cable tool string and used in combination with lifting devices. The trip spear is usually limited in its use to recently drilled wells or to those in which the casing is known to be in sound condition. The risk of failure associated with the use of a casing spear increases with the age of the well and the depth at which it is to be used.

It is always good practice to probe the well with a swage of the same diameter as the spear prior to inserting the latter.

The order of descent into the casing for a trip spear string of tools is: (1) trip spear; (2) fishing jars; (3) sinker bar or drill stem; (4) rope socket, which is attached to the drilling line. The swage would replace the spear in the above string of tools.

Where a drive shoe is attached to the bottom of a casing string to be extracted, it is often advantageous to separate the casing from the shoe. The preferred method for cutting casing is by use of a casing cutter. Some states do not permit the use of explosives inside the casing.

Borehole Bridging

To reduce cost of unnecessary backfilling of long sections of borehole, it is often desirable to establish a temporary bridge in the borehole upon which a permanent cement-based bridge can be placed. No organic materials should be used in either the temporary or permanent bridge—except that specially manufactured devices such as cement plugging tools in which neoprene rubber or plastics are used, are acceptable and these greatly facilitate the work. Some of these devices permit establishing the permanent bridge without first having to set a temporary one.

Abandonment of Flowing Artesian Wells

The flowing artesian well with improperly sealed casing and with water escaping around the outside of the casing either to the surface or to another formation presents a special problem. A necessary first step in bringing the flow under control is to establish a permanent cement seal between the casing and the point or points from which the water is escaping.

In order to place this seal effectively, the flow must be stopped and the water level lowered in the well. This can be accomplished by several methods. Some of these are: (1) pumping the problem well, thereby producing the necessary drawdown; (2) pumping nearby wells, producing the same effect; and (3) introducing high specific gravity fluids at the bottom of the borehole and filling the hole with the fluid until all flow ceases. The method or methods used will depend in part on the shut-in pressure of the well and the depth to which the water level must be lowered.

The sealing of abandoned wells that have a large movement of water between aquifers or to the surface requires special attention. The movement of water may be sufficient to make the sealing with ordinary materials and by the usual methods impractical. In such wells, large stone aggregates (not more than 1/3 of the diameter of the hole) lead wool, steel shavings, a well packer, or cast lead plug or bridge should be used to restrict the flow thereby permitting the placement of appropriate sealing material. If preshaped or precast plugs are used, they should be several times longer than the diameter of the well to prevent tilting. The flow of artesian wells to be abandoned can best be stopped with neat cement or sand-and-cement grout piped under pressure or, in some instances, by the use of a suitable well packer or cast lead plug placed at the bottom of the confining formation immediately overlying the artesian water-bearing zone.

In wells in which the hydrostatic head producing the flow is low and in which there is no escape of water below ground, the movement of water can be arrested by extending the well casing to an elevation above the artesian pressure surface. This permits the placement of sealants and fill materials, after which the casing may be cut off at or below ground level.

Abandonment of Other Borings and Holes

Mineral exploration holes, solution or "in situ" mining wells, dewatering wells, temporary service wells, construction water wells, process wells, and/or other structures that affect the withdrawal from or quality of water in the ground water reservoir, regardless of location or intended life of the structure or hole, should be abandoned as described herein for water supply wells.

Functions of Seals

Three basic types of seals—distinguished by their functions—may be used in a properly abandoned well. They are:

A. Permanent Bridge-Seal: The deepest cement seal to be placed in the well, this seal serves two purposes: it forms a permanent bridge below which considerable unfilled hole may remain and upon which fill material may be safely deposited; and it seals upper aquifers from any aquifer(s) which may exist below the point of sealing. (See Figure 4)

B. Intermediate Seal: This seal is placed between water-bearing formations which have, or are believed to have, different static heads. Its function is to prevent the interaquifer transfer of water. (See Figure 5)

C. Seal at Uppermost Aquifer: This seal is placed immediately above the uppermost aquifer penetrated by the bore hole. Its function is to seal out water from the surface and from shallower formations. In flowing artesian wells, it is designed to prevent the escape of water to the surface, or to shallower formations. (See Figure 6)

Each abandonment effort should be considered an individual problem, and methods and materials should be selected only after detailed study of both construction and geohydrology. Whenever there is doubt about either the construction or the geohydrology involved, the choices of materials and procedures should be those affording the greatest probability for successful sealing.

Aquifer Sealing Criteria

56.100–000–000. *Aquifer Sealing Criteria.* Aquifers shall be filled with disinfected, dimensionally stable materials, compacted mechanically if necessary to avoid later settlement. (Cement, cement-and-sand, and concrete do not require disinfection.)

Disinfection of aquifer fill materials shall be accomplished by using chlorine compounds such as sodium hypochlorite or calcium hypochlorite. Aquifer fill materials shall be clean (relatively free of clays and organic materials) before placement in the well. Disinfection shall be accomplished by dissolving sufficient chlorine compound to produce a calculated concentration of at least 100 ppm available chlorine in double the volume of water

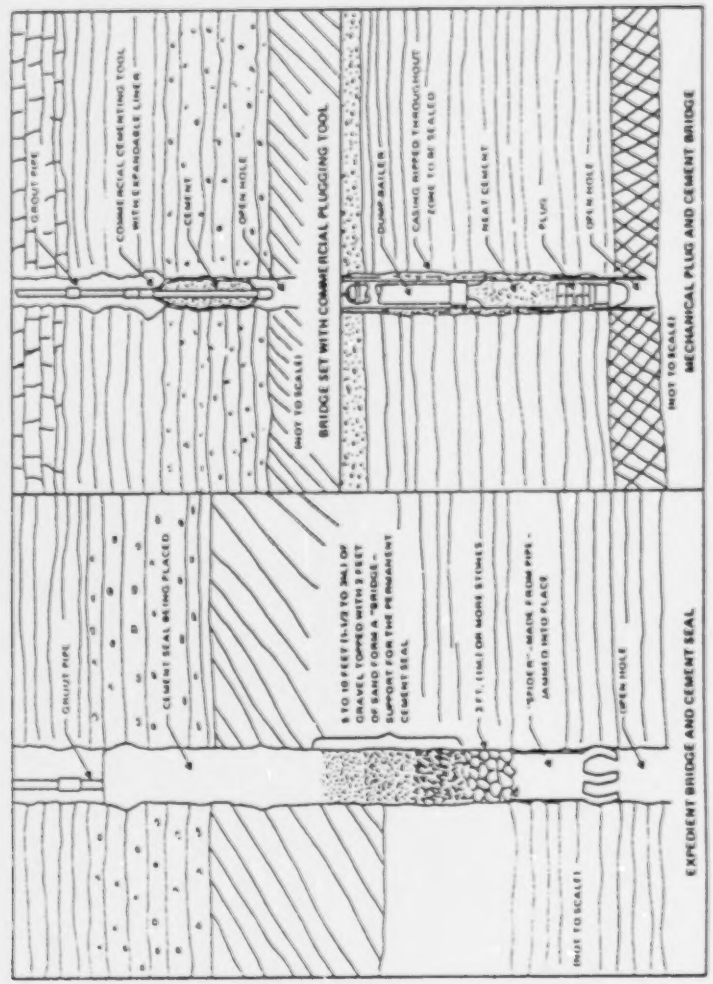

GROUT PIPE
COMMERCIAL CEMENTING TOOL WITH EXPANDABLE LINER
CEMENT
OPEN HOLE
NOT TO SCALE!
BRIDGE SET WITH COMMERCIAL PLUGGING TOOL
CASING RIPPED THROUGHOUT ZONE TO BE SEALED
DUMP BAILER
NEAT CEMENT
PLUG
OPEN HOLE
NOT TO SCALE!
MECHANICAL PLUG AND CEMENT BRIDGE
GROUT PIPE
CEMENT SEAL BEING PLACED
5 TO 10 FEET (1-1/2 TO 3M.) OF GRAVEL TOPPED WITH 2 FEET OF SAND FORM A "BRIDGE" SUPPORT FOR THE PERMANENT CEMENT SEAL
2 FT. (1M.) OR MORE STONES
"SPIDER" - MADE FROM PIPE - JAMMED INTO PLACE
OPEN HOLE
NOT TO SCALE!
EXPEDIENT BRIDGE AND CEMENT SEAL

Figure 4
PERMANENT BRIDGE SEALS

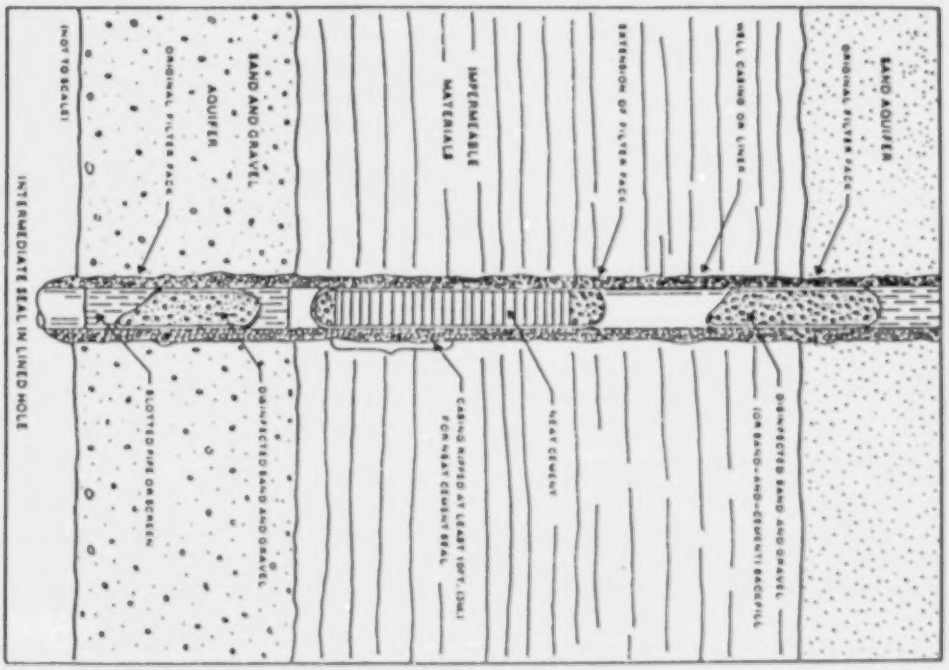
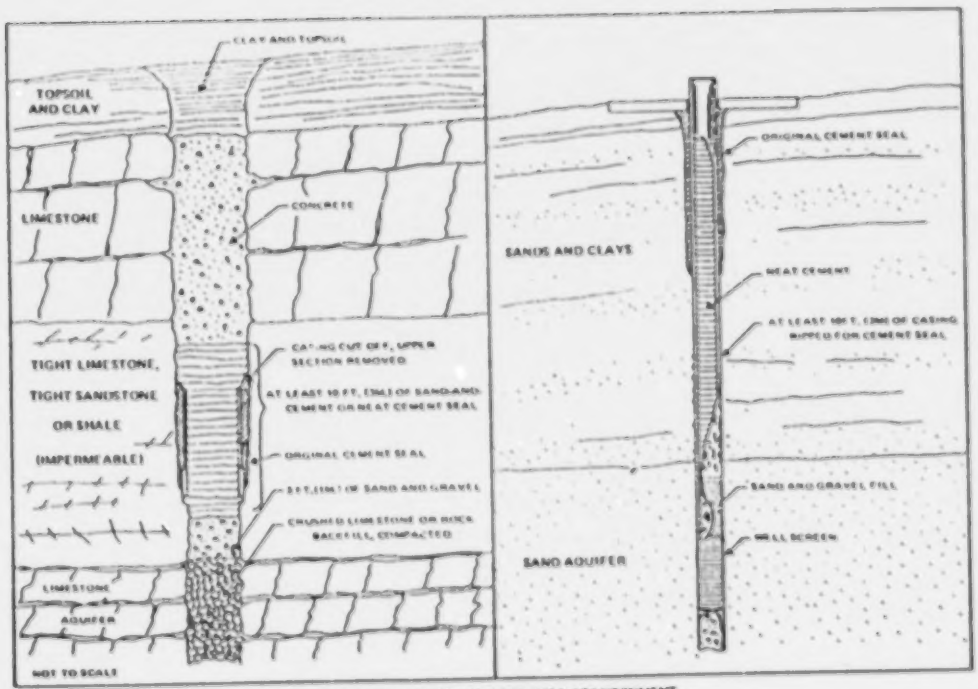


Figure 5
INTERMEDIATE SEALS

138

Figure 6
UPPERMOST AQUIFER



UPPERMOST AQUIFER SEALS IN WELL ABANDONMENT

139

in the well. The fill material shall be placed in the well after the water in the well has been so treated.

PERMANENT BRIDGES

56.010–000–000. *Permanent Bridges.* Permanent bridges may be used to avoid having to fill very deep holes below the deepest point at which a permanent seal is required. Permanent bridges shall be composed only of cement or cement-bearing minerals. The cement shall be allowed to harden for at least 24 hours, if Type I cement is used, or for at least 12 hours if Type III (high early strength) cement is used, before backfilling is continued. Temporary bridges used to provide a base for the permanent bridge shall consist only of inorganic materials—except that patented devices containing expandable neoprene, plastic, and other elastomers, and specifically designed for use in well construction are acceptable.

PLACEMENT OF GROUT

56.001–000–000. *Placement Operations.* Concrete, sand-and-cement grout, or cement grout used as a sealing material in abandonment operations shall be introduced at the bottom of the well or interval to be sealed (or filled) and placed progressively upward to the top of the well. All such sealing materials shall be placed by the use of grout pipe, tremie, cement bucket or dump bailer, in such a way as to avoid segregation or dilution of the sealing materials. Dumping grout material from the top shall not be permitted.

Seals intended to prevent vertical movement of water in the well or bore hole shall be composed of cement, sand-and-cement, or concrete—except that where such seals must be placed within casing or liners, only neat cement grout may be used. The cement-water ratio shall be that specified in Article 48.100-000-000. Cement seals shall be placed by means of pumping through drop pipe or by use of a dump-bailer, with placement beginning at the bottom and continuing upward. The minimum cement seal length, wherever dimensions permit, shall be 10 feet.

56.002–000–000. *Intermediate Seals.* Intermediate seals of cement, sand-and-cement, or concrete shall be placed in impermeable strata between aquifers which are identifiable as, or are suspected of being, hydraulically separated under natural, undisturbed conditions. Once the required cement seal has been installed, the remainder of the impermeable zone or non-producing zone between aquifers shall be filled with sand, sand and gravel, or cement-bearing mineral material.

56.003–000–000. *Seal at Uppermost Aquifer.* A cement, sand-and cement, or concrete seal shall be installed in the least permeable zone immediately above the uppermost water-producing zone. Such seals shall be placed only in quiescent (non-flowing) water. (See Preamble (56) for instructions on how to seal flowing wells.

56.004–000–000. *Seals Placed Within Casing, Liners, Filters, etc.* Seal which must be placed in casing, liners, or filters require special attention. The material between the well and the face of the bore hole shall be thoroughly perforated, ripped, or otherwise disintegrated as the necessary first step. Neat cement only, or neat cement with a maximum of 5 percent by weight of commercially processed bentonite clay, shall be used as the seal. Either of two methods may be used.

1. The calculated amount of grout required to fill the well interval plus the annular space outside the lining shall be placed within the space to be cemented, running the cement through a special cementing packer manufactured for this purpose and installed immediately above the perforated or ripped zone. The cement shall be injected at a pressure calculated to be at least 50 psi greater than the normal hydrostatic pressure within the well at the point of injection.
2. The calculated amount of cement grout required to fill the casing interval plus the annular space outside the lining, plus sufficient cement grout to fill an additional 10 feet of the lining, shall be introduced at the bottom of the interval to be cemented.

PLACEMENT OF FILL

56.000–100–000. *Non-Producing Zones.* Non-producing zones above the aquifer shall be filled with stable materials such as sand, sand-and-gravel, cement, cement-and-sand, or concrete. Non-producing zones above the uppermost aquifer seal shall be filled with materials less permeable than the surrounding undisturbed formations. The uppermost 5 feet of the bore hole (at land surface) shall be filled with a material appropriate to the intended use of the land.

SPECIAL CONDITIONS

56.000–010–000. *Pre-existing Contamination.* An abandoned well which has already been affected by salt water intrusion or any other contaminants shall be considered a special case, and the method of filling and sealing such wells shall be subject to individual review and written approval by the regulatory agency involved.

In the sealing of a double or multiple cased well, the CONTRACTOR shall submit a drawing thereof with a description of the proposed procedure and materials to be used, for prior approval by the regulatory agency involved.

Mineral exploration holes, solution or "in situ" mining wells, dewatering wells, temporary service wells, construction water wells, process wells, and/or other structures which affect the withdrawal or quality of ground water, or the elevation of the water table, regardless of location or intended length of life of the structure, shall be abandoned according to standards and minimums as described herein for water supply wells.

WELL ABANDONMENT RECORDS

56.000–001–000. ***Recording Location of Abandoned Well or Bore Hole.*** Before equipment is removed from the site, the exact location of the abandoned well or hole shall be determined and recorded, "tying in" the location with permanent reference points, or as prescribed by the state or local regulatory agency. All information relative to the abandonment procedures and the location of the abandoned well shall be prepared and assembled as prescribed by the state or local regulatory agency, with copies supplied to the respective agency and the owner of the land.

METHOD OF PAYMENT FOR ABANDONMENT

56.000–000–100. ***Method of Payment.***

Option A (Lump Sum): All of the work performed under this Article (56) shall be paid for as a lump sum.

Option B (Time and Materials): All of the work performed under this Article (56) shall be paid for on the basis of the price bid for well construction equipment per hour plus materials at cost plus percent of add-on bid.

Option C (Unit Price): All of the following work performed under this Article (56) shall be paid for at the unit price bid per hour for well construction equipment plus the cost of any materials and/or subcontracted services at the invoice price plus percent of add-on bid:

Well Abandonment ..... Unit Price/Foot

APPENDIX E

MONITOR/BOREHOLE DETAILS

APPENDIX E: MONITOR / BOREHOLE DETAILS

BOREHOLE NO.	MONITOR NO.	DEPTH (m)	DIAMETER (1) (mm)	COMMENTS
84-3	--	37.8	203	4.0 m into bedrock, sealed
84-4	--	35.5	203	1.1 m into bedrock, sealed
84-5	--	34.6	203	1.0 m into bedrock, sealed
85-5	1	40.4	255	3.0 m into bedrock
	2	35.4	203	
	3	26.8	203	
	4	17.9	203	
	5	5.5	203	
85-8	1	39.5	255	3.5 m into bedrock
	2	33.2	203	
	3	26.8	203	
	4	16.2	203	
	5	5.5	203	
	6	25.9	255	
	7	16.8	255	
	8	25.4	255	
	9	15.7	255	
	10	5.3	203	
	11	9.4	203	
85-17	--	10.0	223	Sealed
85-18	--	10.0	223	Sealed
WATER WELL #1	--	Unknown	Unknown	Drilled bedrock well
WATER WELL #2	--	~37	Unknown	Drilled bedrock well

(1) Diameter in overburden

APPENDIX F

REPORT FROM SCIENTIFIC
WASTE STRATEGIES, INC.

SWS SCIENTIFIC WASTE STRATEGIES, INC.
Hazardous Waste Specialists

August 13, 1987

Mr. Ted Rannie
Gartner Lee Associates, Ltd.
140 Renfrew Drive
Markham, Ontario
CANADA L3R 6B3

Dear Mr. Rannie:

The purpose of this correspondence is to report our opinion regarding the proper grout selection for the proposed hazardous waste landfill to be located near the West Lincoln Township, Ontario. Our recommendations are founded on information which you communicated by phone and on the excerpts from Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics, Baseline Conditions - Volume 1, a report by Gartner Lee Associates, Ltd., which you telefaxed on July 24, 1987. Consequently, the engineering appropriateness of our recommendations is limited by the accuracy of that information. The recommendations are the consensious opinion of my colleagues and I who represent three different, but complementary fields of study, materials science, civil engineering, and organic chemistry.

The specific recommendations are:

1. The use of a grout composed of Canadian Type 10 (ASTM Type I) Portland cement plus 3-4% (by weight) bentonite is not advised. EPA recommends Portland cement grouting for monitoring wells. It is presumed that Portland cement is recommended because it will seal the well bore hole against percolation of contaminated water from below and/or permeation of clean water from above, and because it will maintain structural integrity for many years. Certainly the latter assumption is valid under most conditions. However, it is our opinion that the former assumption may not be valid because of shrinkage which occurs when Portland cement hardens. Shrinkage could cause the formation of an annulus around the hardened grout through which fluid transport could occur. Special care must be taken to prevent the formation of a shrinkage annulus.

2. All PVC borehole liners should be removed from ungrouted holes prior to grouting. It is possible that a shrinkage annulus was formed between the outside of the PVC liner and the concrete well casing. It would therefore be poor practice to grout the PVC liner and leave a shrinkage annulus on the outside.

3. All monitoring well boreholes which have already been grouted with Canadian Type 10 Portland should be re-bored and re-grouted with a more suitable grout. As discussed in Recommendation 2, the PVC liner should also be removed.

4846 Tulane Drive • Baton Rouge, Louisiana 70808 • (504) 769-1484

4. Three grouts are commended as acceptable alternatives:

(a) Five Star, Special Grout 150 - This is a proprietary formulation sold by the U.S. Grout Corporation, 401 Tillson Rd., Fairfield, CT, USA. Special Grout 150 is a non-shrinking grout. The base material is ordinary Portland cement (ASTM Type I). A patented chemical additive decreases the amount of shrinkage. There are two disadvantages to this alternative. First, the mixture is non-shrinking, but not expansive. It would be desirable in this application to use an expansive cement to increase likelihood that a seal between the grout and the well casing walls is formed. Second, it is our opinion that hazardous waste landfills should avoid the use of proprietary formulations in grouting or solidification materials.

(b) Employ the expertise of a special grouting formulator - Reputable firms include Halliburton Well Services and Dowell-Schlumberger. Either of these firms can provide a suitable grout. However, proprietary formulations are likely to be recommended unless otherwise specified.

(c) Use a grout formulated with Type K expansive cement as the primary component - It is our opinion that this is the best alternative because a simple, non-proprietary cement is used. The expansive formulation which contains anhydrous calcium sulfoaluminate will minimize the possibility that shrinkage annulus will be formed. Mix design procedures follow normal practice (American Concrete Institute, ACI 211.2-69 for lightweight concrete). In order to achieve a minimum of 6,000 psi compressive strength at 28 days, it is recommended that a water/cement (w/c) ratio of 0.42 - 0.45 be used. Prolonger mixing times can increase the early rate of formation of the expansive mineral phase (ettringite). This is an undesirable effect since early ettringite formation can decrease the amount of expansion in the hardened state. Consequently, excessive mixing is to be avoided. A small amount by bentonite (3-4% by weight) can be used to increase plasticity. The amount of water should be increased if bentonite is added. An increase in the w/c ratio by 0.05 is recommended. Of course, these mix recommendations should be tried in the laboratory prior to batching.

The number of Type K cement suppliers is small. A reputable vendor is Texas Industries, Inc., P.O. Box 400, Arlington, TX 76010, USA.

I hope that these recommendations meet your needs. Please call me if you required further consultation.

Sincerely,

Harvill C. Eaton

Harvill C. Eaton, Ph.D.
Vice-President/Materials Scientist

ss:17-1

RECEPTOR

- shallow, large diameter well used for domestic water supply (the nearest such well is 250m from the Preferred Site

CONTINGENCY

- should a potential for ground water quality impacts be identified, shallow ground water collection systems can be installed on-site as a contingency measure
- alternate water supplies could also be provided for both quantity and quality impacts

REGULATORY BOUNDARY

- Reasonable Use Concept is applicable policy for ground water quality at site boundary (applies to ground water resources only)
- for non-health related parameters, the quality must not be degraded by an amount in excess of 50% of the difference between background and the Provincial Drinking Water Objectives
- for health related parameters, 25% is used instead of 50%
- no further impairment of quality allowed for parameters already exceeding Provincial Drinking Water Objectives
- for many parameters, particularly organic compounds, there are no Provincial Drinking Water Objectives - these are being assessed from a risk perspective by OWMC's Risk Consultants

OVERALL FACILITY MONITORING

- monitoring in buffer zone for early warning of site boundary and off-site impacts
- monitoring of:
  - changes in ground water flow in weathered silt and clay and bedrock aquifer
  - changes in ground water quality in weathered silt and clay and bedrock aquifer

LANDFILL MONITORING

- monitoring of landfill performance
- monitoring of:
  - quality of shallow ground water in cover
  - changes in ground water flow and quality below landfill (can be accomplished by monitoring wells and soil sampling)
  - performance of underdrain if operated

LINK TO SURFACE WATER PATHWAY

should contamination of shallow ground water in cover occur it may discharge to surface water in swales which in turn could discharge off-site via storm water detention pond

CONTINGENCY

collect and treat surface water

MITIGATION

- shallow entombed engineered landfill concept selected to minimize movement of leachate away from site
- surficial seepages of leachate will not occur because landfill does not rise above surrounding grade
- potential for leachate to enter shallow ground water in weathered silt and clay minimized since waste residues are placed below the most weathered zone
- design allows site to be operated in either passive or active mode
- modification of leachate quality may be possible through changes in waste treatment, solidification formulations and/or exclusion of certain wastes

MONITORING

- monitoring of Central Operating area impacts at boundaries
- monitoring of:
  - changes in ground water flow in bedrock aquifer
  - changes in ground water quality that may indicate the presence of contaminants

SO

- accessible
- example -

M

- multiple le protection traffic, co paved surf
- spill respo immediate able resid levels as lations

PROPERTY BOUNDARY

TRENCH TYPE MONITOR

SILT AND CLAY COVER

- leachate produced by solidified treated waste residue

LANDFILL SOURCE

UNDERDRAIN

UNWEATHERED SILT AND CLAY

SOURCE

potentially contaminated ponds

MONITORING

for presence of contaminants below lined ponds to check for liner leakage

PATHWAY

- potential for contaminant movement laterally in shallow ground water flow through the weathered silt and clay
- extensive lateral flow not considered probable
- most active flow near surface where infiltration would constantly "flush" contaminants resulting in high dilution rates

PATHWAY

- potential for contaminant migration upward against infiltrating water by diffusion, into shallow ground water of cover

PATHWAY

- leachate will move downward with ground water flow but at very slow rates
- ground water flow time to bedrock aquifer is several hundreds to thousands of years
- silt and clay soils maximize retardation (sorption), filtration, precipitation and degradation of leachate constituents

PATHWAY

- old boreholes and wells may provide a "short-circuit" for contaminant to reach bedrock aquife

MITIGATION

- boreholes will be sealed prior to facilities construction

LINK TO SURFACE WATER PATHWAY

- should contamination of shallow water occur it could seasonally discharge to ditches offsite and be carried to streams

CONTINGENCY

shallow ground water collection on-site could collect and treat surface water

NDFILL MONITORING

- monitoring of landfill performance
- monitoring of:
  - quality of shallow ground water in cover
  - changes in ground water flow and quality below landfill (can be accomplished by monitoring wells and soil sampling)
  - performance of underdrain if operated

MITIGATION

- shallow entombed engineered landfill concept selected to minimize movement of leachate away from site
- surficial seepages of leachate will not occur because landfill does not rise above surrounding grade
- potential for leachate to enter shallow ground water in weathered silt and clay minimized since waste residues are placed below the most weathered zone
- design allows site to be operated in either passive or active mode
- modification of leachate quality may be possible through changes in waste treatment, solidification formulations and/or exclusion of certain wastes

MONITORING

- monitoring of Central Operating area impacts at boundaries
- monitoring of:
  - changes in ground water flow in bedrock aquifer
  - changes in ground water quality that may indicate the presence of contaminants

SOURCE

potentially contaminated ponds

MONITORING

for presence of contaminants below lined ponds to check for liner leakage

PATHWAY

- potential for contaminant migration upward against infiltrating water by diffusion, into shallow ground water of cover

UNDERDRAIN

WAY

e downward with
but at very slow

time to bedrock
hundreds to

maximize retard-
iltration, preci-
dation of leachate

UNWEATHERED SILT AND CLAY

SOURCE

- accessible spills
- example - tanker truck overturn

MITIGATION

- multiple levels of engineering protection, e.g., slow one way traffic, controlled access, paved surfaces etc.
- spill response to provide immediate clean-up to acceptable residual contaminstion levels as required by regulations

MONITORING

- shallow monitoring at strategic locations in Central Operating Area on a case-by-case basis in response to spills or leaks
- monitoring for:
  - shallow ground water quality - non-aqueous phase products and ground water flow

PATHWAYS

- contaminants may move locally to the base of the weathered silt and clay over site life (50 years)
- migration into the unweathered silt and clay will be limited to very short distances over site life (50 years)

PATHWAY

- old boreholes and wells may provide a "short-circuit" for contaminants to reach bedrock aquifer

MITIGATION

- boreholes will be sealed prior to faciilities construction

SOURCE

- inaccessible spills
- example: sump rupture during spill

MITIGATION

- multiple levels of engineering protection, e.g., double containment, automatic level alarms, routine inspections, floor washing, etc.

SOURCE

- leaks
- example: pipe joint leakage

MITIGATION

- multiple levels of engineering protection, e.g., above-ground pipe racks, routine inspections, systems monitoring, etc.
- clean up at detection to acceptable residual contamination levels as required by regulations

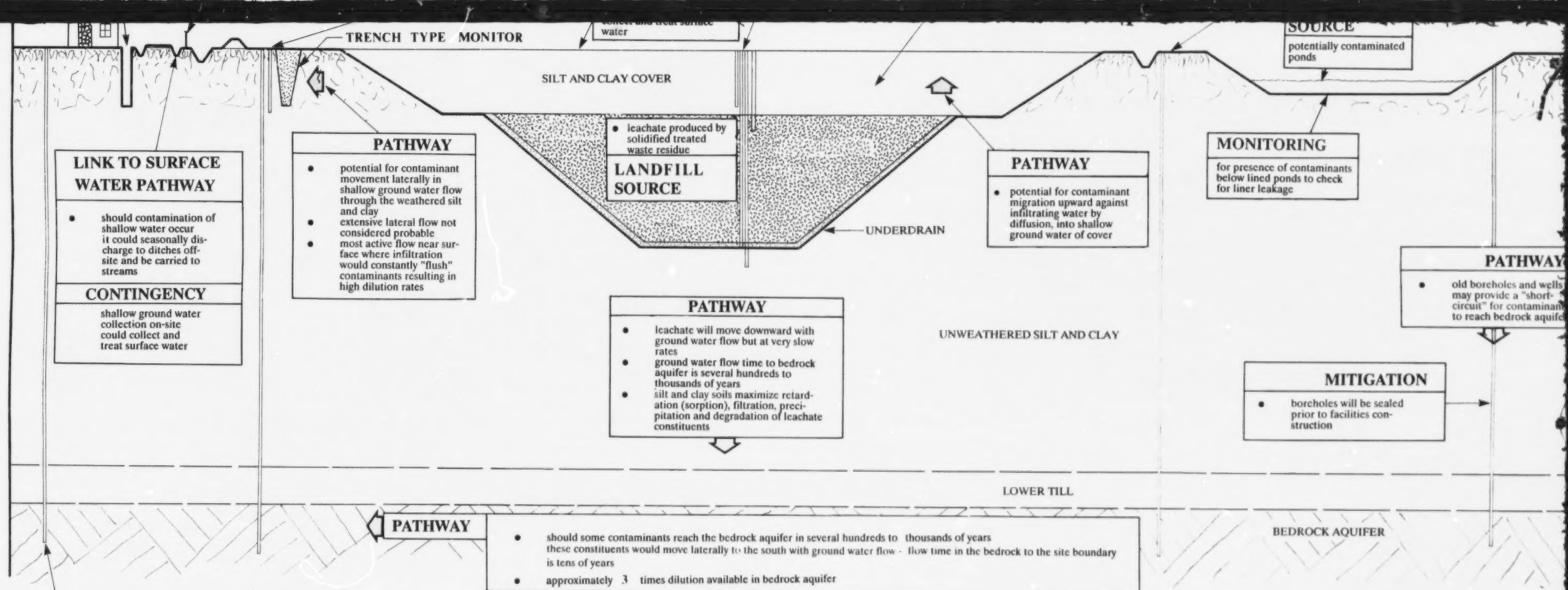
Building

Pipe Rack

WEATHERED SILT AND CLAY

MITIGATION

- following active life of the site, decommissioning will clean-up contaminated soils to acceptable levels based on OWMC's impact assessments and as required by regulations


TRENCH TYPE MONITOR
water
SILT AND CLAY COVER
SOURCE
potentially contaminated ponds
LINK TO SURFACE WATER PATHWAY
should contamination of shallow water occur it could seasonally discharge to ditches offsite and be carried to streams
CONTINGENCY
shallow ground water collection on-site could collect and treat surface water
PATHWAY
potential for contaminant movement laterally in shallow ground water flow through the weathered silt and clay
extensive lateral flow not considered probable
most active flow near surface where infiltration would constantly "flush" contaminants resulting in high dilution rates
leachate produced by solidified treated waste residue
LANDFILL SOURCE
UNDERDRAIN
PATHWAY
potential for contaminant migration upward against infiltrating water by diffusion, into shallow ground water of cover
MONITORING
for presence of contaminants below lined ponds to check for liner leakage
PATHWAY
old boreholes and wells may provide a "short-circuit" for contaminant to reach bedrock aquife
PATHWAY
leachate will move downward with ground water flow but at very slow rates
ground water flow time to bedrock aquifer is several hundreds to thousands of years
silt and clay soils maximize retardation (sorption), filtration, precipitation and degradation of leachate constituents
UNWEATHERED SILT AND CLAY
MITIGATION
borcholes will be sealed prior to facilities construction
LOWER TILL
PATHWAY
should some contaminants reach the bedrock aquifer in several hundreds to thousands of years these constituents would move laterally to the south with ground water flow - flow time in the bedrock to the site boundary is tens of years
approximately 3 times dilution available in bedrock aquifer
BEDROCK AQUIFER

RECEPTOR	CONTINGENCY
• bedrock well used for domestic water supply (the nearest down-gradient well is presently 500m to the south of the Preferred Site	• should a potential for ground water quality impact be identified, contingency measures such as purge wells can be installed in the bedrock aquifer to collect the ground water for treatment • alternate water supplies could also be provided for both quantity and quality impacts.

Gartner Lee Limited

potentially contaminated ponds

PATHWAYS

- contaminants may move locally to the base of the weathered silt and clay over site life (50 years)
- migration into the unweathered silt and clay will be limited to very short distances over site life (50 years)

WEATHERED SILT AND CLAY

MONITORING

for presence of contaminants below lined ponds to check for liner leakage

PATHWAY

- potential for contaminant migration upward against infiltrating water by diffusion, into shallow ground water of cover

UNDERDRAIN

PATHWAY

- old boreholes and wells may provide a "short-circuit" for contaminants to reach bedrock aquifer

MITIGATION

- following active life of the site, decommissioning will clean-up contaminated soils to acceptable levels based on OWMC's impact assessments and as required by regulations

WAY

- downward with but at very slow
- time to bedrock hundreds to
- maximize retard-filtration, preci-dation of leachate

UNWEATHERED SILT AND CLAY

MITIGATION

- boreholes will be sealed prior to facilities con-struction

LOWER TILL

BEDROCK AQUIFER

rock aquifer in several hundreds to thousands of years
the south with ground water flow - flow time in the bedrock to the site boundary

le in bedrock aquifer

FIGURE 1 - 5 SCHEMATIC DIAGRAM OF GROUND WATER CONTAMINANT SOURCES, PATHWAYS, RECEPTORS, MONITORING, MITIGATION AND CONTINGENCIES